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Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401

General Technical
Report INT-175

December 1984



Managing Intermountain Rangelands — Research on the Benmore Experimental Range, 1940-84

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PREFACE

The Benmore Experimental Range in north-central Utah was set aside for rangeland research in the 1930's because it was representative of vast areas of land that needed rehabilitation and improved management. These lands, originally in native sagebrush-grass vegetation, were important sources of livestock forage in spring and fall. Their value had declined seriously. Unregulated use and overuse had caused preferred grasses and forbs to decline and unpalatable shrubs to increase. Research was undertaken to find practical ways of rehabilitating and managing these lands.

Over a 44-year period, the Forest Service, Utah State University, the Soil Conservation Service, and others conducted many studies at Benmore—mostly on vegetation and livestock. The results have been documented in over 80 reports cited in this publication. Many of the findings can be applied to other parts of the Intermountain area with similar vegetation, soils, and climate.

This report provides rangeland managers and users with a summary of the 44 years of research at Benmore. This distillation of information may be helpful in planning and decisionmaking. It is a guide to research results—recognizing that rangeland managers and users have neither ready access to the literature nor the time necessary to search it. Those who want more detailed information can follow up with specific reports cited in the References section.

We hope that managers and users of western rangelands will find this a useful reference.

ACKNOWLEDGMENTS

This publication was developed under an agreement with the Utah Department of Agriculture and was conducted through the active cooperation of the Range Science Department, Utah State University. It was partially funded by a grant from the Four Corners Regional Commission.

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RESEARCH SUMMARY

The Benmore Experimental Range was set aside, fenced, and seeded to improved grasses during the late 1930's. This land was typical of much of central Utah, which had been overgrazed by livestock or plowed, farmed, and abandoned. State and Federal agencies and local citizens saw a need for research to find better ways to rehabilitate, use, and conserve the vast areas of sagebrush-grass rangelands such as those at Benmore. Research began in 1941 under a cooperative agreement among the Forest Service, Utah Agricultural Experiment Station, Soil Conservation Service, and the Bureau of Plant Industry. During the 44 years of work summarized here, many researchers analyzed alternative ways of rehabilitating the land by controlling brush and planting improved grasses, controlling reinvasion by brush, managing rehabilitated lands, and controlling effects of grazing livestock. By following recommended practices, managers can successfully increase the productivity of the land and the livestock. The authors have summarized the findings of 44 years of research from over 80 separate research reports. Results of the Benmore experience can be used in planning and decisionmaking for Intermountain rangelands such as those of central Utah. Many of the findings about basic relationships and improvement of management methods may be useful in analyzing problems of other Intermountain rangelands. Management guidelines summarizing each major section of the report appear at the start of each section.

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Managing Intermountain Rangelands — Research on the Benmore Experimental Range, 1940-84

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INTRODUCTION

The Benmore project is only a dot on the map in comparison to the vast acreage of rangeland surrounding it. On millions of acres of land in this state (Utah) alone, resources in the way of soil, sunshine, and moisture are being squandered in the production of sagebrush and a few other unpalatable plants. How long we . . . let this sort of thing continue depends not on our learning how to do the job, but only awaits the time when we will have developed the enterprise to take advantage of our opportunity.

—Harry K. Woodward, 1948

Since the 1940's the science and art of range management has developed immensely. Notions once based on "horse sense" have been modified and refined over the years by practical experience and hard research. This research, conducted by a variety of agencies and groups, has helped increase our knowledge about how best to administer America's vast rangelands. The Benmore Experimental Range, for example, has been the location of numerous studies extending over four decades that explored techniques for improving western rangelands and how they can best contribute to livestock production. Despite these efforts, many thousands of acres of range are producing less than their potential—the result of years of abuse or neglect.

The condition of western rangelands has improved generally since the 1930's, but the task of rehabilitating our depleted rangelands is still a formidable one. Much of this land lies west of the Rocky Mountains where the climate is harsh for vegetative growth. In fact, 17 Western States comprise about 70 percent of America's rangelands—in all, over 700 million acres. Utah itself is a major range State with over 45 million acres of rangeland constituting nearly 86 percent of the State's land area. Of this range acreage, 36 million acres (80 percent) are publicly owned. Some of these lands are in need of rehabilitation and good management is paramount to high productivity.

Utah is not unique among Western States, however. Every state has rather large acreages of depleted rangelands that now support only a fraction of their former livestock numbers. Moreover, the scant vegetation on

some areas is unable to prevent the erosion of valuable topsoil, increased flooding, loss of wildlife habitat, and declining range productivity.

This condition exists on both public and private rangelands. While many clearly recognize the importance of bringing lands into their potential to produce, few have known what proven methods to employ. In many cases, research findings have not been made readily available to managers. In other cases, the prospect of actually harming the range even further through improper management has led to an unwillingness to experiment. To range workers, grass is both the key to prosperity and a means of maintaining a stable livestock industry.

Even with good methods for restoring the West's depleted ranges, some disagreements stem from the characteristics of rangelands themselves. Some lands are difficult to manage because rainfall is low and erratic, and temperature extremes are often great. Rangelands that receive between 12 and 14 inches (30.5 and 35.6 cm) or more of annual precipitation can be reseeded with good success. The risks increase rather dramatically if precipitation falls below these levels.

But the ranges that receive adequate precipitation also receive the greatest pressure from livestock. Many of these ranges lie in the foothill areas and are grazed both in the spring and fall. These so-called spring-fall ranges not only receive grazing pressure at two times during the year, but the spring period also coincides with the time of greatest nutrient requirements when animals are nursing calves or lambs. Lack of green grass in the springtime, then, leads to nutritive deficiencies in livestock.

Prior to regulated grazing, competition for nutritious forage led to range wars and the deterioration of both spring and summer ranges by grazing these areas before plants had sufficient growth. Some range workers realized that if spring ranges could be reseeded with an early growing, grazing-tolerant grass, livestock and range alike would benefit. Not only would range productivity and condition improve, but conservation of soil and water, improvements in wildlife habitats, and reductions in flooding would also result.

The Benmore Experimental Range was established in the middle 1930's to address this need and develop sound range management techniques that would improve grazing capacities on foothill rangelands of the West.

ESTABLISHMENT AND ADMINISTRATION

The early history of the Benmore area shows that this land was unadapted to successful dry farming (see appendix A for history of Benmore). Its usefulness was limited to the grazing of livestock, and because it was in the spring-fall belt, research became a primary need. Such spring-fall areas were recognized as the limiting factor in successful range livestock production operations in Utah.

Twenty-eight 100-acre (40.5-ha) plots were set aside for fencing and seeding. In addition, a 280-acre (113.3-ha) holding pasture was established. Employees of the Works Progress Administration (WPA) built most of the facilities at the range station between 1935 and 1940. The facilities included a 5,000-gal (18,927-liter) storage tank, two storage reservoirs, pipelines to all 28 pastures, and a well. Finally, 160 acres (64.8 ha) were set aside for reseeding studies along with a 20-acre (8.1-ha) tract that would be left untreated to illustrate what had occurred on the abandoned dry farming lands.

The Benmore pastures remained unseeded until fall 1938 and spring 1939. The pastures were plowed, the sagebrush removed, and seed spread into light stands of cheatgrass in the following mixtures (see appendix B for a list of common and scientific names):

Type of seed	Lb/acre (kg/ha)
Crested wheatgrass	2.5 (2.80)
Smooth bromc	1.0 (1.12)
Slender wheatgrass	0.5 (0.56)
Western wheatgrass	0.5 (0.56)
Tall oatgrass	<u>0.5 (0.56)</u>
Total	5.0 (5.60)

At a later date, bulbous wheatgrass was broadcast at a rate of 1 lb/acre (1.1 kg/ha). Of all these species, crested wheatgrass adapted best to conditions at Benmore. However, it was slow to establish on the pastures, perhaps because of the low initial application rate and because of competition from annual weeds (fig. 1). Thus, the poorest stands were later reseeded with crested wheatgrass at a rate of 4 lb/acre (4.5 kg/ha) in 1941 and some pastures even a second time in 1945. All stands were protected from grazing by domestic herbivores until 1943 when some stands were judged ready for use.

The Benmore seedings, then, represent some of the West's oldest crested wheatgrass stands. Presently, crested wheatgrass comprises about 95 percent of the available forage. Traces of bulbous bluegrass and western wheatgrass can be found as well as some perennial



Figure 1.—Perennial crested wheatgrass invades a patch of annual weeds, namely cheatgrass and Russian thistles.

forbs and various annuals. Big sagebrush and rubber rabbitbrush are present in varying amounts but eaten very little by cattle and then only in the fall.

In the late 1940's, Utah State University researchers seeded smaller pastures to Russian wildrye, and intermediate, tall, pubescent, and crested wheatgrasses. These comprised the area between the main road leading to Benmore and the larger crested wheatgrass pastures, as shown in figure 2.

During the 1930's, Benmore was shuffled between several administrative agencies. Some of these included the National Resources Committee, the National Resources Board, the Resettlement Administration, and the Bureau of Agricultural Economics. Finally, the area was turned over to the Soil Conservation Service for management until 1954 when the Forest Service acquired it.

From the beginning, a number of agencies cooperated to conduct research at the Benmore Experimental Range (Walker 1944). The Utah Agricultural Experiment Station, the Soil Conservation Service, the Forest Service's Intermountain Forest and Range Experiment Station, and the Bureau of Plant Industry in 1941 signed a cooperative agreement on the future of research at Benmore. Specifically, these organizations committed themselves to studying the rehabilitation of abandoned cultivated lands through reseeding, management, and conservation of soil and water, and to ascertaining "the best management methods and practices for such lands, both during and after rehabilitation and restoration."

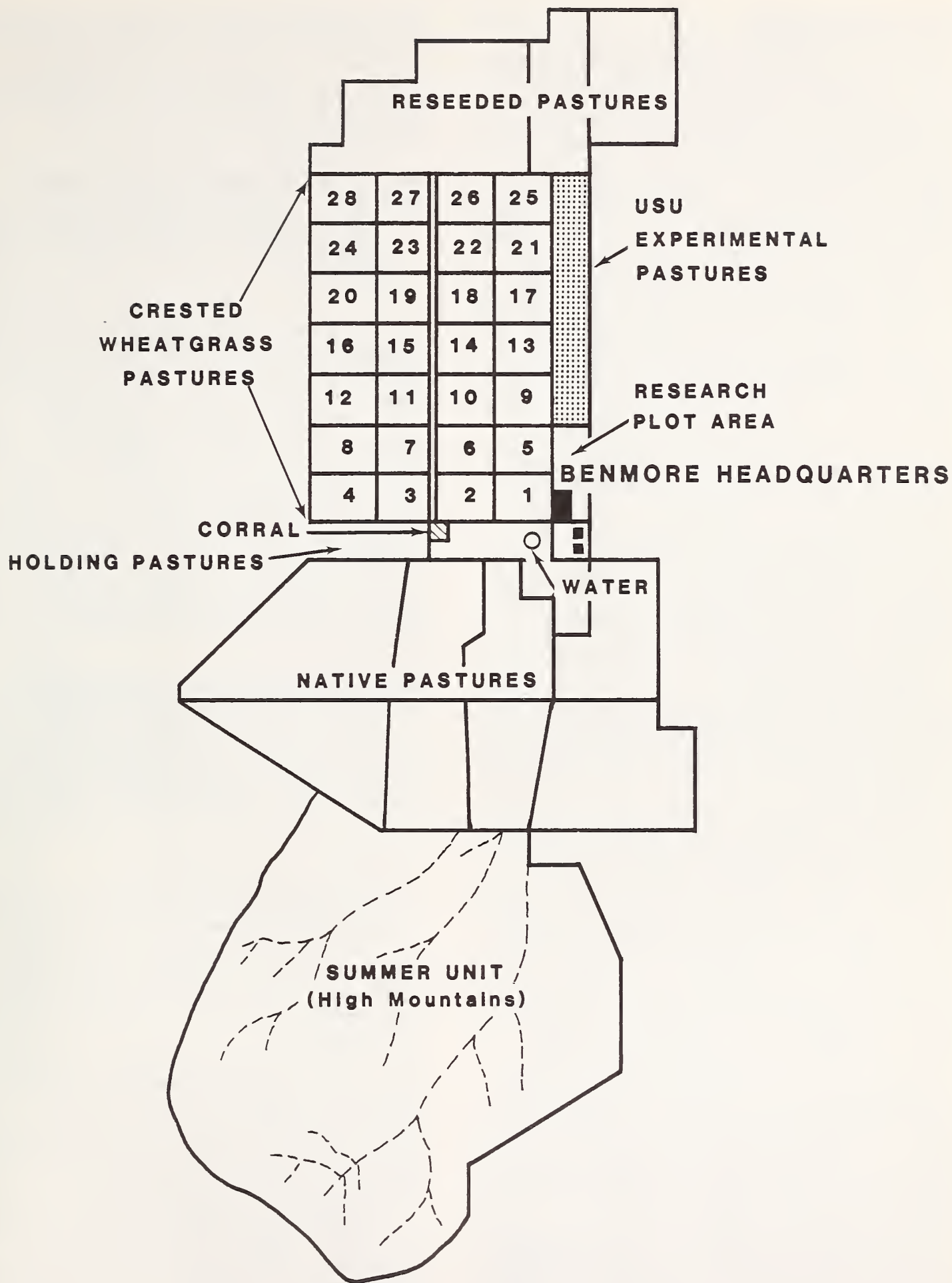


Figure 2.—Facilities at Benmore, Utah, include 28 reseeded crested wheatgrass pastures (water is piped to each), reseeded pastures, holding pastures, Utah State University seeded pastures, and native pastures and mountain pastures research plot areas.

SITE DESCRIPTION

Located in the southeast corner of Tooele County in Utah, the Benmore Experimental Range is in Rush Valley on typical spring-fall range (Frischknecht and Harris 1968). The experimental area lies between salt-desert shrub range to the north and mountainous summer ranges to the south and west.

The Benmore pastures are approximately 5,800 ft (1 768 m) in elevation and receive an annual average precipitation of approximately 13 inches (33 cm). Rain-fall in Rush Valley is rather erratic and a high evaporation rate further reduces precipitation effectiveness. Since 1911, when recordkeeping began, Benmore has received a low precipitation level of 6.8 inches (17 cm) in 1956 and a high of 19.01 inches (48 cm) in 1913. Half the precipitation generally occurs between December and May while 40 percent falls during the growing season.

Benmore has an average annual temperature of 48.4° F (9.1° C) with a maximum of 61.5° F (16.4° C) and a minimum of 35.4° F (1.9° C). Generally, the first killing frost occurs by September 25 and the last by May 30. Summers are usually dry, hot, and windy.

Soils at Benmore are unconsolidated clay loams, light gray to pale brown, and calcareous. The organic content is relatively low, and there is a dense claypan layer found at about the 17-inch (43-cm) level. Upper horizons of the soil are moderately permeable. But because the soil is fine textured, it crusts over easily after a rain. Thus, seedlings can have difficulty penetrating this baked surface.

The topography at Benmore is generally level, but the area is dissected by intermittent channels and swales. Drainage is to the north on about a 2 percent slope and sheet erosion can be severe in the absence of sufficient plant cover.

Native vegetative growth in this area of Rush Valley is diverse. Grass species include bluebunch wheatgrass, Sandberg bluegrass, thickspike wheatgrass, western wheatgrass, Indian ricegrass, bottlebrush squirreltail, Great Basin wildrye, and annual cheatgrass. Forb species are equally diverse and those most prominent include lupine, Utah sweetvetch, longleaf phlox, hoary phlox, low fleabane, desert globemallow, groundsel, hawksbeard, false dandelion, locoweed, and annuals such as Russian thistle, pepperweed, and halogeton. Common woody species are big sagebrush, rubber rabbitbrush, yellowbrush, juniper, and some pinyon.

When it was purchased in 1934 under the Central Utah Dryland Adjustment Program, the Benmore Experimental Range was typical of thousands of acres of land in the Intermountain West that were producing little forage but were still used for grazing. Carrying capacities on these lands were extremely low, and available forage was of low quality.

When Benmore was established, range management on foothill ranges was still in its infancy, and little was known of range improvement techniques. Because the range had been broken up and native grasses had all but vanished, sagebrush had come to dominate vast areas of formerly prime grazing land. One early settler had experimented with burning, but more systematic studies of techniques were called for. In restoring de-

pleted rangelands to grass, a number of problems would be encountered: clearing brush; preparing the soil; time, rate, depth, and method of seeding; adaptation of grass species; and method and intensity of grazing. The Benmore Experimental Range was ideal for investigating these questions.

REMOVING RANGELAND BRUSH

Studies at Benmore may be taken as "a fair example of what may be expected from reseeded sagebrush lands in Utah if they are properly managed."

—Lorin E. Harris and others 1950

Restoring deteriorated spring-fall rangelands is no simple task. Experience shows that perennial grasses seeded into dense stands of sagebrush or cheatgrass do not become established. The land must be properly cleared and the soil prepared before seeding. Otherwise, failures can result and grazing capacity may actually be reduced rather than increased. While it is possible to eliminate competing species with large machinery, such operations are limited to tillable land and are often costly. In addition, seed prices tend to be high and the probability of success often low, mitigating against trial-and-error efforts by livestock operators. Thus, results of experiments conducted at Benmore can be useful to ranchers and resource managers in many parts of the West.

Because the condition of the soil at seeding is critical, alternative methods of brush removal were extensively investigated at Benmore. These experiments were carried out to ascertain the best and least expensive methods of brush removal on shrub-dominated rangelands, including plowing, burning, harrowing or raking, the use of a brush cutter, and subsequently, spraying with herbicide.

Guidelines on Brush Removal

Reclaiming deteriorated rangelands or abandoned farmlands must begin with effective methods of brush removal. Because of the risks involved and the possibility of failure, methods that eliminate, as completely as possible, competing species should be employed. Based on experiments at Benmore, the following guidelines are suggested:

1. When deciding which lands to treat, managers should choose the best for the initial treatment: good soil, level topography, absence of trees.
2. If money permits, a brushland plow, wheatland plow, or offset disk will work best to eradicate brush species. For the latter, plowing should be done in two directions with the disks set at an angle.
3. Burning is an economical method of brush eradication and is highly effective given the right conditions. The weather should be dry, somewhat windy; there should be good ground fuel to carry the fire, and a wide fireline to stop the fire.
4. After treating an area (either by mechanical or natural means), it should be rested at least until the fall of the second growing season before any grazing is allowed. This will enable perennial grasses to establish

themselves to compete effectively with other less desirable species.

Site Preparation

Mechanical methods.—These methods, including disk plows, wheatland plows, and offset harrows have all been tested at Benmore with varying degrees of success. Early experiments with cheatgrass reported by Stoddart (Benmore Field Day Report 1947, unpublished) indicated that disking with a wheatland plow in fall after seed germination resulted in complete eradication of cheatgrass. Disking in summer and late spring were both effective in reducing cheatgrass stands, but less so than fall disking.

On sagebrush, Stoddart found that disking one way with the disks set straight gave only 35 percent sagebrush kill but disturbed soil only to a minimum. Disking two ways with the disks set at an angle resulted in 95 percent sagebrush eradication.

Stoddart (Benmore Field Day Report 1947, unpublished) found that railing twice kills less brush than heavy plowing; a 50 percent kill is about average. Similar results were also found for the log harrow. Stewart (Benmore Field Day Report 1947, unpublished) reported that rabbitbrush was not so completely killed by railing, plowing, or burning as was sagebrush. It sprouts readily and tends to become a major nuisance in reseeded areas. Rabbitbrush also readily invades thin stands of grass.

In later experiments reported by Cook (1966a), disking one way eliminated only 80 percent of the sagebrush, but plowing twice using either a two-way offset or a wheatland plow killed nearly all the sagebrush on the plots. After two growing seasons, sagebrush cover on these latter plots was only 0.3 percent. The brushland plow developed by the USDA Forest Service from the Australian stump-jump plow controlled sagebrush in one operation.

Cook also found that shredding with a roto-beater and roto-knives was effective in controlling large sagebrush plants but not in eliminating the smaller ones. After 5 years, sagebrush had reestablished itself on these plots to comprise 25 percent of the cover.

Frischknecht (1978b) also reported that a Servis brush cutter was effective in killing large sagebrush plants, but small plants and those with prostrate branches survived. Seventeen years later it was difficult to distinguish between the treated and untreated plots.

On larger species, such as pinyon and juniper, chaining can be used. While this method is effective in removing these species, it is costly and should be employed only on thick stands of trees where the expenditures for such range improvements may be justified. Generally, chained areas also must be piled and then plowed or drilled for most complete removal of trees. Results of some chaining research conducted at Benmore were reported by Parker (1971) and Parker and Frischknecht (unpublished report).

Burning.—Treating depleted rangelands with fire is probably the cheapest method of brush removal, but it also poses problems. Brush is hard to burn if small,

when spaced far apart, and when ground fuel is sparse or absent. Fire may destroy more than what was intended, eliminating both desirable and undesirable plants. Fire can also aid the invasion of undesirable plants, such as rabbitbrush and snakeweed. If the fire does not carry well, the removal of undesirable species may not be complete enough to permit successful reseeding of perennial grasses. Finally, the effort requires careful planning and management to avoid delay in the effort. Reliable firelines, workers to control spot fires, and a permit from the fire warden are required in most cases.

Burning experiments of various kinds have been conducted at the Benmore Experimental Range with varying degrees of success. Such experiments were initiated because of the high costs of other methods of brush removal and because many researchers have speculated that natural fire controlled the range of woody species and maintained the grasslands the early American pioneers reported finding.

Burning cheatgrass with a flame thrower before seed formation dramatically reduced the stand of this annual, according to Stoddart (Benmore Field Day Report 1947, unpublished). Natural burning in the early spring (mid-June) was much less effective than burning with a flame thrower because natural burning cannot be done until after the seed has developed enough to germinate. Burning before the seed is formed is difficult because the plants are still partially green, which requires special flame burners. However, early burning was, without exception, more effective than later burnings. Early summer burning (early July) had but slight effect on cheatgrass. Early August burning was somewhat effective probably because of a hotter fire, and material reduction was noted on the trial plots. Fall burning (October) did not reduce cheatgrass stands the following spring.

Stoddart reported that burning is one of the best and most cost-effective means of removing sagebrush. The ash fertilizer left after the burn was also a good seedling booster. Almost complete eradication was obtained during good burning weather. From his observations, June 30 was about the first date that sagebrush could be burned with good results. Depending upon the year, complete burns are then possible from that date until about October 1. Adequate wind, especially, was a critical factor in achieving a good burn. Stoddart reported that even in midsummer burning was impossible before 9 or 10 a.m. because winds were only slight.

Frischknecht (unpublished report), in cooperation with the Wasatch National Forest, conducted experimental burns to control sagebrush and invading junipers on native range at Benmore. Conditions are shown in table 1. The West Dutch burn on September 17, 1970, was conducted about 1 month later than had been planned because of the high hazard of burning in August. Conditions at the time of burning were not adequate for a thorough burn on big sagebrush. Owendry weight of sagebrush leaves and flower stalks was only 44 percent compared to between 68 and 78 percent owendry weight for various grasses and 53 percent for broom snakeweed. Good burns were obtained in draws, but the fire died out on ridges where grass cover was less dense.

Table 1.—Burning conditions for three prescribed burns at Benmore

Name of burn	Date	Beginning p.m. time	Temperature	Percent relative humidity	Windspeed
West Dutch	9/17/70	3:00	70° F (21° C)	27	0- 6 m/h (0-9.7 km/h)
Middle Dutch	8/24/71	4:30	82° F (28° C)	23	0- 5 m/h (0-8.1 km/h)
East Dutch	8/22/72	2:00	84° F (29° C)	14	12-15 m/h (19.3-24.1 km/h)

Prior to burning, density of invading junipers averaged 73 trees per acre (180/ha) on permanent plots 0.1 acre (0.04 ha) in size. Twenty-four of 60 (40 percent) permanent plots were unburned. However, 32 percent of the trees under 8 ft (2.4 m) tall burned, compared to only 19 percent of the trees over 8 ft.

In 1971, air temperatures and relative humidity were more conducive to burning the Middle Dutch area than the previous year on West Dutch, but light wind was once again limiting a complete burn. Because of light wind, a center firing method was used in hopes of creating a convection column that would draw fire in from the perimeter (fig. 3). Although, a good convection column developed, parts of some ridges did not burn.

The most complete burn was on August 22, 1972, on 350 acres (141.6 ha) known as East Dutch. Although 0.40 inch (1.02 cm) precipitation had fallen the night of August 18, by burning time on August 22 the fine fuel moisture was 6 percent, air temperature 84° F (29° C), relative humidity 14 percent, and windspeed 12 miles per hour (19.3 km/h) from the southwest. At 1 p.m., winds were from the north at 12 miles per hour, and skies were clear. By 1:30 p.m., a cloud cover appeared over the Sheeprock Mountains to the south, and winds shifted down-mountain from that

direction. Crews had been prepared to fire the area with hand torches from the north, but when the wind suddenly shifted, crews proceeded to touch fire to the area along the south and west sides, beginning at the southwest corner of the area at 2 p.m. (fig. 3). Within 45 minutes, the entire area had been burned over. All trees on permanent plots were killed.

From this experience, Frischknecht established requirements for successful burning of sagebrush grass ranges where junipers are invading: less than 20 percent humidity, temperature 80° to 95° F (27° to 35° C), and windspeed 10 to 15 miles per hour (16.1 to 24 km/h). Under these conditions, good fire lanes were required, and control crews were necessary to control spot fires that might arise from fire whirls carrying firebrands across the fire lanes.

More extensive studies were started when many persons claimed that pinyon, juniper, and other brushy species had extended their range since settlement because of human interference with natural fires. Some have even estimated that Utah's pinyon-juniper cover has increased in the sagebrush-grass communities and now comprises about 30 percent of the entire State. Left unchecked, these woody species invade the lower sites and compete with grasses that provide the vast bulk of



(A)



(B)

Figure 3.—(A) A convection column was developed by center firing under conditions of very light wind on Middle Dutch burn. (B) Winds of 12 to 15 mi/h (19.3 to 24.1 km/h) resulted in a rapid, more complete burn on East Dutch.

forage for domestic and wild herbivores. Thus, Barney and Frischknecht (1974) examined vegetation on 28 burns of various ages and determined the successional patterns following a fire. The data collected, it was believed, would help range managers understand both the role of fire in the ecosystem and rates of invasion by various plant species.

The results of Barney and Frischknecht's survey suggest a number of ways that fire can be an important aspect of range improvement techniques:

1. The cover value for both cheatgrass and annual forbs was highest immediately after a burn, but then declined the first 22 years after the original burn. From then on, their percentage in the composition remained fairly constant and rather low.

2. Without artificial reseeding, perennial grass (usually western wheatgrass and bluebunch wheatgrass) tended to increase rapidly the first 5 or 6 years after a burn, to maintain a consistent level over the next 40 years, and then to decline as woody species increased. The lowest grass cover was observed in the oldest burns. As expected, there was a direct correlation between an increase in juniper tree cover and a decrease in grass cover over time.

3. Sagebrush occurred on all burns, regardless of the age, indicating that it can reinvade rather quickly following a fire if a seed source is nearby.

4. Trees take somewhat longer to establish themselves, remaining absent on burns for about 5 years, except for a few young plants. These plants, moreover, were found under or adjacent to crowns of trees that had been killed by fire—indicating that they probably originated from residual seeds.

5. The rate of invasion for trees was slower in young stands having few seed-producing trees at the time of the fire. Most trees became established from residual seeds soon after a fire originated. These researchers concluded that rates of shrub invasion and succession are also influenced by other factors not directly observed on the burn sites. For example, the rate of succession depends on the kinds and number of seed-dispersing agents—of which water and animals are the most important. Succession would be slow if it were only accomplished from the burn edge. This is especially true for large burns.

In addition, large herbivores can exert a strong influence on the rate of shrub invasion. Heavy grazing following a fire, as a Benmore settler noticed in the 1920's, will reduce the vigor and cover of perennial grasses and increase the invasion of woody species. Trampling by animals is also a factor in planting viable juniper seeds, although a minor one.

On the basis of this study, fire can be a valuable management tool to restore shrub-dominated rangelands at low cost. Although a burned area may initially be dominated by cheatgrass and other annuals, perennial grasses will establish themselves and remain vigorous for about 40 years (fig. 4). Trees begin to dominate burn areas after this time and eventually crowd out all but a few grasses. Even sagebrush can be crowded out by pinyon and juniper trees.

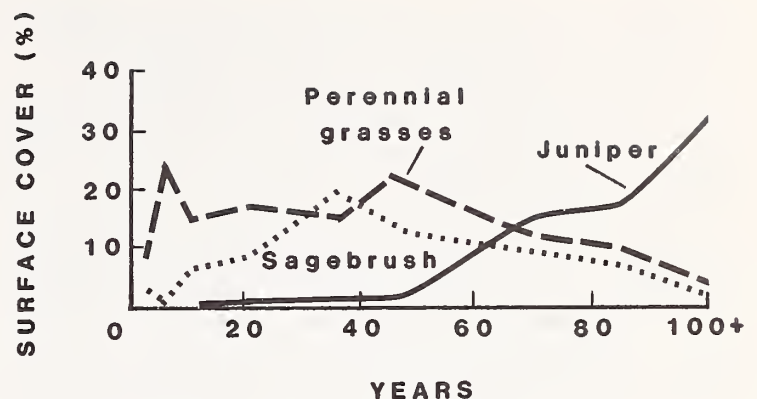


Figure 4.—Surface cover of juniper, perennial grasses, and sagebrush by age of burn (after Barney and Frischknecht 1974).

SEEDING RANGELANDS

As we have seen, research at Benmore helped develop brush removal practices that were economically sound and effective. However, at the time Benmore was established, little information was available about proper methods of reseeding depleted rangelands. Managers were unsure about what seeds would do best and provide good forage for domestic livestock. Obviously, there was a pressing need for data that would serve as a guide for successful management. Benmore was an ideal testing site to explore these problems.

During the 1930's vast areas of the West were being reseeded with an introduced grass known as crested wheatgrass. As a contribution to the western livestock industry, crested wheatgrass has been the forage discovery of the past century. It is remarkably free from diseases such as stem rust and ergot, and is ready for grazing as much as 3 weeks before cheatgrass. It is also winter hardy and not known to show frost injury (Benmore Field Day Report 1949, unpublished). Introduced from Eurasian Russia, crested wheatgrass adapts to the arid and semiarid conditions of the Western United States. Its abundant and nutritive growth from April until the end of June, and the greening characteristics it shows in September, October, and November following late summer or fall rains, make it admirably suited to restore spring-fall ranges depleted by abuses. In addition, by seeding crested wheatgrass and other grasses on depleted lands, especially dry spring-fall ranges, it is possible to keep a great many livestock off the higher ranges in the mountains until the vegetation there is ready to be grazed.

Guidelines on Seeding

Since 1942 studies at Benmore have sought the best methods of developing spring ranges for the Intermountain West. Some studies have focused on methods of seeding: time, rate, depth, and manner of seeding. Although research at Benmore has pointed to some successful techniques for restoring depleted ranges, there is no simple "cookbook" approach that will work

in all areas. Climatic, soil, topographic, and weed competition considerations must be recognized. However, the studies suggest the following guidelines:

1. Crested wheatgrass produces the best forage stands, is preferred by cattle in the early spring, and remains vigorous over long periods.

2. Plowing twice with an off-set disk eradicates nearly all sagebrush. When done in the fall, it results in higher rates of emergence and survival for all perennial species. A hazard of fall plowing, especially late fall near sagebrush seed maturity, is the likelihood of a new crop of sagebrush plants the following spring (Frischknecht and Bleak 1957).

3. Broadcast seeding prior to sagebrush eradication produces its best results in the fall, but drilling is superior when done in the spring (March 15 to April 15). A semideep furrow drill proves to be the best of all methods tested.

4. The soils should be firm and moist before drilling to produce the best results. In addition, seeds should be planted no more than 1 inch (2.5 cm) in depth. Drilling should never follow immediately after plowing on spring seedings, but has proven successful in the fall if not seeded too deep.

5. Emergence and survival rates will often be low. One should not expect more than 5 percent of the seeds planted to result in established plants 3 years later. Crested wheatgrass has an especially low establishment rate but has a high survivability rate thereafter.

6. Seeding should be done in moderate intensities (4 to 6 lb/acre or 4.5 to 6.7 kg/ha) and in moderate densities (drill rows 14 to 21 inches or 35.6 to 53.3 cm apart) to produce the best results. Such intensities will reduce invasion of annuals, ensure deep root development, lower plant fiber content, and produce thick stands that are preferred by cattle.

7. Contrary to earlier beliefs, mixed grass seedings should be avoided. Rather, pastures should be planted with one type of grass, and then cattle can be rotated among pastures as the season and palatability change.

8. If seed production is a consideration, presowing vernalization can help achieve flowering from spring planting the first year. It also can speed spring emergence and improve survival rates, which is probably more important than increased seed production.

Best Seeding Circumstances

Two studies by Cook and Stoddart (1947) demonstrated that reseeding depleted rangelands once dominated by sagebrush is not only feasible but can be very successful. The researchers concluded:

1. There must be a firm seedbed; after plowing, the ground should be allowed to sit several weeks before drilling, otherwise the loose soil tends to bury the seed too deeply during drilling.

2. The best time to seed in the spring appears to be after a rain storm so the ground is firm and moist, preferably in early April.

3. Seed should be no more than 1.5 inches (3.8 cm) deep, and preferably only 1 inch (2.5 cm) deep, especially seeds such as crested wheatgrass.

4. About 2 years must be allowed for these new stands to establish themselves before grazing can be permitted.

Cook and Stoddart's (1947) first study, initiated in 1943, used two species: crested wheatgrass and western wheatgrass. These two species were planted in all possible combinations involving early-fall, late-fall, and spring-season planting; high, medium, and low intensity; shallow and medium depth; and by using both an ordinary and a deep-furrow range drill for seeding. All seeding was done on fallow ground.

Analysis of these seedings in 1947 revealed some surprising results:

1. Spring seeding, in all cases, was superior to any other time of year, producing about 30 to 50 percent more grass.

2. The deep-furrow drill was distinctly superior to the ordinary grain drill, yielding about one-third to one-half more grass.

3. Crested wheatgrass produced better stands than western wheatgrass under all treatments at Benmore.

4. Planting depths of 1 to 1.5 inches (2.5 to 3.8 cm) gave about the same yields as more shallow plantings of 0.5 inch (1.3 cm).

5. Seeding at high intensity (7 to 9 lb/acre or 7.9 to 10.1 kg/ha) produced higher yields than at low intensity (4 to 6 lb/acre or 4.5 to 6.7 kg/ha), but the differences were not significant.

Not content to rest with these findings, Cook and Stoddart (1950) conducted a second study from 1944 to 1945 to observe other species and test different methods of planting. Three species of grass were used: tall, intermediate, and pubescent wheatgrass. Again, plantings were made in both spring and fall at shallow and medium depths and at low and medium intensities. This study revealed:

1. The best stands were produced first by pubescent wheatgrass and next by tall, with intermediate last.

2. All species produced excellent stands under the proper seeding methods, but pubescent and intermediate may produce denser stands because they form a sod. Tall wheatgrass is a larger plant and can yield an equal amount of forage overall.

3. Mixtures of early and late growing species would produce a pasture with a longer grazing season than monocultures.

4. Shallow planting and high density seeding generally gave better results than did deep planting and low intensity, but again, the differences were not great.

5. Early spring planting far outyielded fall planting and resulted in nearly three times as many plants in all treatments.

Seeding Techniques

The studies only began to address some of the important research questions posed by range rehabilitation. Cook and Stoddart (1950) then designed studies on seeding methods and concluded from them:

1. Fall broadcasting gives results comparable or sometimes even better than drilling, and at a lower cost.

2. Broadcasting must be done correctly and in conjunction with some effective means of brush removal, preferable plowing.

3. Drilling of seed in the spring, especially with the semideep furrow drill, produces better results than broadcasting.

Broadcast seeding.—One seeding study was designed to test three methods of brush eradication followed by broadcast seeding of four species of grass: crested, tall, intermediate, and pubescent wheatgrass. Sagebrush was treated by a wheatland plow, tumbling-log harrow, and rail. The rationale for testing broadcast seeding was twofold: drilling is expensive and broadcasting can be used on a variety of landscapes.

Overall, when all treatments and all plantings (fall or spring) were considered, all species produced about the same percentage emergence, ranging from 17.4 for tall wheatgrass to 20.8 for intermediate. In addition, all species under all methods of broadcasting produced higher emergence rates from the fall seeding during the first year. However, the results from subsequent years were variable, so in some cases the spring seeding produced as well as the fall seeding. From this study, Cook and Stoddart also identified the following:

1. Broadcast seeding before sagebrush eradication produced better results than broadcasting after for both spring and fall plantings for all species except crested wheatgrass on plowed land. Again, it appeared that too much soil fell back over these smaller seeds before germination.

2. During the first season, crested wheatgrass produced better results from fall seeding than any of the other species. However, during the next year (1948 to 1949) all species seemed equally well adapted to fall seeding.

The differences apparently were due to climatic factors. The first year of the experiment there were no spring rains to settle the soil. During the second year, spring rains made seedling emergence more likely. Thus, a variety of factors may influence the results of reseeding rangelands: species of grass, weather, method of brush eradication, and method of planting.

Drilling seed.—To test the latter variable to a greater extent, Cook and Stoddart (1950) initiated another study on the Benmore plots. The four varieties of wheatgrasses previously tested were again used but were planted with three types of drills on plots that had been (1) disk-plowed 1 month prior to planting, (2) disk-plowed 1 year prior to planting, and (3) railed 1 year prior to planting. The three types of drills used were the unitiller, the surface drill, and the semideep furrow drill. The comparative results:

1. The semideep furrow drill produced the best results under all conditions. The unitiller produced the poorest results, especially for crested wheatgrass seed. Again, the unitiller allowed too much soil to cover the seed for successful seedling emergence.

2. Plowing during the summer before fall planting was superior to plowing or railing a year earlier without further treatment to control annual weeds. Railing also produced the poorest results.

Seedling Emergence Rates

Cook and Stoddart (1951) reported on seedling emergence after different methods of soil preparation and planting. Three methods of brush eradication (plowing, railing, and tumbling log harrow) were used with fall and spring broadcasting of the four varieties of wheatgrasses. Emergence rates for seeds ranged from 3.65 percent for pubescent wheatgrass to 5.0 percent for crested wheatgrass. Again, fall broadcasting produced higher emergence rates than did spring seeding. Moreover, the method of brush removal directly affected overall seedling survival rates, which appeared to be correlated with the number of brushy species remaining:

Method of brush removal	Percent kill rate	Percent seedling survival
Plowing	95	52
Railing	40	26
Log harrow	40	19

In spring 1949, Cook and Stoddart (1951) set out to determine the effects of soil firming on seedling emergence. Again, the four species of wheatgrass were planted by five methods on sagebrush range—one half cleared by plowing, the other half by railing. One series of plots was then firmed with a cultipacker previous to and after planting. As expected, emergence was significantly greater for all four species on all plots that had been firmed by the cultipacker regardless of whether the seed had been drilled or broadcast. Emergence rates for firmed plots were 46 percent of the viable seed compared to 24 percent on the unfirmed plots. Again, the semideep furrow drill produced slightly better results than did the surface drill.

This study showed that there was no great difference in the percent emergence or survival among species by method of brush removal at the end of the first year. However, long-range results are often more important than immediate results. Seedling survival over the long term may be directly related to competing vegetation on an area the first summer. Plowing 1 month before planting appears to produce the best results. Moreover, while a firm seedbed is beneficial to seedling emergence, soils that are too fine in texture and too wet may compact to a hard crust and impede emergence.

Drilling of all seed types in the spring produced more than four times the number of seedlings than fall seeding. Yet, survival of fall seedlings was 40 percent compared with only 11 percent of the spring seedlings. Still, the higher emergence percentage on spring-planted plots resulted in higher numbers of established plants.

Cook and Stoddart determined that the average seedling emergence rate for all four species of wheatgrasses combined was only 11 percent. Of this number, only about one-fourth survived into the second season. Thus, even under proper methods of soil preparation and seeding, only about 3 percent of the viable seed planted actually became established plants by the third growing season.

Despite this low survival rate, in a few years crested wheatgrass and pubescent wheatgrass were closed stands.

Intermediate and tall wheatgrass at first produced good stands, but then began to show interspaces that filled with cheatgrass. The crested and pubescent wheatgrass stands were still good 15 years after the original seedings, but the other two stands were in only fair condition. While seedling success was highest for pubescent wheatgrass, production of all four species at the end of 3 years was 464 lb/acre (520.1 kg/ha) for crested, 404 lb/acre (452.8 kg/ha) for pubescent, 333 lb/acre (373.3 kg/ha) for tall, and 304 lb/acre (340.8 kg/ha) for intermediate wheatgrass.

Intensity and Density of Seeding

With some of the questions about time and depth of seeding investigated, researchers then focused on intensity and density of seeding. Knowing the optimums, the most economical and efficient use could be made of seed on depleted rangelands. Leonard (1964) and Cook and others (1967) conducted separate studies over 9 years on grass stands with different seeding rates. Four wheatgrass species were studied: crested, pubescent, tall, and intermediate. Seeds of these species were planted in both fall and spring. In addition, four intensities of seeding were combined with four densities (row spacings) to derive 16 rates of seeding.

Intensities, per 25 linear feet (7.6m) of drill row:

Low	= 161 seeds
Medium	= 322 seeds
High	= 483 seeds
Very high	= 644 seeds

Densities (row spacing):

Low	= 28 inches (71.1 cm)
Medium	= 21 inches (53.3 cm)
High	= 14 inches (35.6 cm)
Thick	= 7 inches (17.8 cm)

Germination.—On the average, Leonard (1964) and Cook and others (1967) found that fall was the best for broadcast seeding and early spring best for drilling. The 2-year studies found that an average of 4.7 percent of viable seeds planted in the fall emerged as seedlings the following spring. Of 100 seeds planted in the spring, 12.8 seedlings emerged. Crested wheatgrass rates of emergence were significantly lower than the other three species for both seasons, averaging only four seedlings per 100 seeds. Other species averaged about 10 seedlings per 100 seeds.

In fall plantings, the number of established plants per 100 viable seeds decreased as row spacing became wider. Spring plantings demonstrated the same tendency, except for the 28-inch (71.1-cm) spacing, which resulted in somewhat higher numbers of established plants than did the 21-inch (53.3-cm) spacing. Reasons for this deviation are not clear. Tall wheatgrass was found to do much better when planted in the spring under all intensities and spacings. It produced 2.5 times as many plants in the spring compared to the fall.

All varieties of seed were also placed in a germinator to monitor overall germination potential. After 5 days, intermediate wheatgrass germinated 73 percent of the seed compared to pubescent with 70 percent, tall with 66 percent, and crested wheatgrass with only 30 percent.

However, after 20 days in the germinator, these differences largely disappeared.

For field conditions, these researchers reported that thin stands seemed to experience higher germination rates (nearly 60 percent) compared to thick stands (55.4 percent), although these differences were not large.

Both Leonard (1964) and Cook and others (1967) noted that some seeds that did not emerge in the first spring season were lost due to early emergence in the fall and subsequent winter kill or seed rot. In addition, some seeds were also consumed by birds, insects, or rodents.

Although the results are not conclusive, fall plantings appeared to have a higher percentage of emergence when the drill rows were closely spaced. Spring seeds demonstrated similar tendencies except for the least dense spacing—28 inches (71.1 cm)—which exhibited the same percentage of emergence as the most dense. Why this should occur is not clear. On the average, only 8.7 percent of the seeds planted ever emerged. Moreover, this study noted that increased density of seeding or intensity of seed within the drill row decreased the percent of seed that produced established plants the first year. This conclusion was true for all four species and for both seasons of planting. Hence, there appeared to be competition between seedlings within the drill rows. Overall, then, seeding intensity appeared to have a greater effect on stand density over time than drill row spacing. This finding suggests that seeds planted in widely spaced rows will not produce a closed community as rapidly as the same quantity of seed planted in narrowly spaced rows.

Of the fall-planted seeds, an average of 20 percent germinated but did not emerge. For spring-planted seeds, the figure was 27.4 percent. Crested wheatgrass also demonstrated a greater tendency toward rotting in spring plantings than in fall plantings. The other three species rotted more in the fall. The average for all four species for rotting was 9 percent. In all cases, more ungerminated seeds were recovered from those planted in the spring.

Generally, there was a lower survival rate the more intense the seeding, although there may have been more total plants per plots due to the heavier seeding rate. As the number of seeds planted per unit of drill row increased, the number of plants that became established per 100 viable seeds planted decreased. This relationship was true for all four species and times of planting. Competition between seedlings did not affect germination but did affect growth and survival.

Herbage production.—Average herbage yield for all intensities and densities was 452 lb/acre (506.6 kg/ha) of air-dry herbage. The best results, of course, occurred when precipitation was higher than normal: 1951 to 1952 and 1954 to 1955. Yet, the general effect of season on yields was not that significant. Tall wheatgrass produced more from spring plantings at all intensities. Crested wheatgrass produced the most herbage of all varieties after three seasons, whereas tall wheatgrass produced the least, perhaps because the site was too dry for tall wheatgrass. As expected, high intensity and close drill row spacing produced the most herbage

per acre at the end of three seasons. Conversely, forage production decreased when a given volume of seed was spread out over a larger area.

Survival of established seedlings from the first season into the second year depended upon competition for moisture and drill row spacing. Average rates of survival for intensity and density into the second year were about 50 percent, but varied as widely as 30 percent for those planted in the fall to 68 percent for those planted in the spring. Analyzed by season of planting for all four species combined, on the average 53.2 percent of the first-year plants from seed planted in the fall survived into the second season. Only 20.3 percent of the first-year plants from spring planted seeds survived into the second year. The earlier germination of the fall planted seeds appeared to help these plants get established before the summer dry periods developed.

When expressed as a percent of seeds originally planted, the second-year survival rates are not impressive. Spring plantings averaged only 3.6 percent compared to 2.5 percent for seeds planted in the fall.

For individual species, though, the results are more illuminating. Crested wheatgrass had the highest percent survival rate into the second year (58.5 percent of plants present the first year). Yet, this species also had the lowest percentage of germination:

Species	Percent established 2d year
Pubescent	3.8
Intermediate	3.1
Tall	2.9
Crested	2.4

In addition, these studies noted a decline in the survival rates between the first and the second years with an increase in drill row spacing. Closer spacing may reduce competition from annuals and not induce severe competition between young perennial grasses. Yet, there is a limit. There appeared to be a lower survival rate the more intense the seeding.

Survival rates were also noted for the third season. Again, crested and pubescent wheatgrasses both exhibited the best survival rates. By the end of the third season, these two species had experienced only a 15 percent mortality rate over the second season compared to 30 percent for intermediate and tall wheatgrass. On the average, only 2.4 percent of the viable seeds planted the first year produced established plants by the third year. Therefore, any use should be light until after this period.

After three seasons, pubescent wheatgrass had the best stands with fewer annual weeds than the other species. Crested wheatgrass stands, however, were very comparable, and stand improvements from the third to the ninth season were, of course, greatest for both pubescent and crested wheatgrass. Tall and intermediate wheatgrass stands declined in quality over this period, and interspaces filled with annual weeds.

At the end of the ninth season, average production from the fall and spring plantings was approximately the same. Still, no plot was producing at its full potential.

Moreover, regardless of species, fall plantings showed about twice as much brush invasion as plots planted in the spring. Why this result occurred is not clear.

Seedhead production.—Leonard (1964) and Cook and others (1967) found that the number of seeds per head and number of seedheads per plant were directly affected by stand density in young plantings. Thick stands produced 58.3 and 20.2 seedheads per plant for crested and tall wheatgrass, respectively. Thin stands, on the other hand, resulted in 121.5 and 33.5 seedheads for these two species, respectively. Seedheads were also longer (4.5 inch or 113.4 mm) in thin stands when compared to seedheads in thick stands (4.1 inch or 103.8 mm).

Soil moisture.—As in Leonard's study, Cook and others found no significant difference in the percent soil moisture between thin and thick stands. They concluded that lateral roots of grasses in both stand densities use moisture in equal amounts to at least an 18-inch (45.7-cm) depth. In addition, no significant differences were found in the depth of roots between thin and thick stands, numbers of roots per plant reaching maximum depth, or depth of root concentration.

Chemical content.—Plants in thin and thick stands differed in chemical composition. In thick stands, plants were somewhat higher in total protein, phosphorus, and total gross energy, while thin stands were slightly higher in lignin and cellulose concentrations. These differences were related to the leaf-to-stem ratio, which is directly influenced by stand density.

Utilization.—Intermediate wheatgrass was the most preferred grass all season long of the four species used. Livestock also showed a slight preference for thick stands over thin stands, 28 percent compared to 22 percent. These differences became more marked during late summer where preferences changed to 25 percent and 16 percent, respectively. Pubescent wheatgrass stands were not preferred by cattle under any circumstances.

During the mid-1960's, Cook (1966a) conducted further studies on the proper use and development of foothill ranges in Utah. He concluded that the highest potential land should be seeded first. In addition, a good species should be selected that, on the basis of research, can thrive under conditions for that site. As previous studies have demonstrated, crested wheatgrass is an adaptable species and produces good stands of herbage. Russian wildrye, while tolerant of salts in the soil, produces frail seedlings with high mortality rates. Seedlings may require double the regular seeding rate if satisfactory stands are to be established.

Cook concluded that mixing grass species has not been the most desirable practice on foothill ranges because the stand soon converts to the species of lesser palatability. In contrast to studies that argued for mixed seeding, Cook concluded that it would be far better to rotate livestock among separately seeded pastures of pure stands.

He also observed that the method of brush eradication could ultimately determine the success or failure of any range rehabilitation project. Complete brush eradication by plowing prior to planting permits the seeded species

to reach full potential in about 5 years. Partial eradication requires additional herbicide treatments in 7 to 8 years, and the full potential of any site could be delayed for 10 to 11 years.

Based on studies at Benmore, Cook also surmised that drilling seed is superior to broadcasting it. The semideep furrow disk drill with 12- to 14-inch (30.5- to 35.6-cm) spacing was better than the ordinary single disk surface grain drills. Deep planting should be avoided. Cook also suggested that when 3 to 5 percent of the seeds remained uncovered and showing in or at the edge of the drill row, the seeds had not been drilled too deeply. Broadcasting works best when done in the fall prior to chaining, railing, or harrowing, but requires 70 percent more seed than drilling to obtain good stands the first time.

Cook (1966a) also reported results of research conducted on brush eradication and seeding methods. Plowing twice using either a two-way offset or wheatland plow removed nearly all sagebrush. The production figures in the fall for three species of wheatgrasses broadcast following these treatments are:

Species	Production Lb/acre (kg/ha)
Crested wheatgrass	841 (943)
Intermediate	574 (643)
Tall	507 (569)

Rates of sagebrush reinvasion for these plots was only 0.3 percent.

In trials at Benmore, Cook also found that plowing only once with a wheatland plow eliminated about 80 percent of the sagebrush, but sagebrush reinvaded at a much more rapid rate, resulting in progressively lower production figures. At the end of 3 and 5 years, the three species had the following yields that demonstrate this decline:

	Lb/acre (kg/ha)	
	3 years	5 years
Crested	621 (696)	273 (306)
Intermediate	689 (772)	307 (344)
Tall	604 (677)	167 (187)

On the other hand, plots that were treated with a brushland plow produced the following yields at 3- and 5-year intervals:

	Lb/acre (kg/ha)	
	3 years	5 years
Crested	628 (704)	1,199 (1 344)
Intermediate	400 (448)	821 (920)
Tall	464 (520)	834 (935)

On these plots, less than 0.5 percent of the ground cover was comprised of reinvading sagebrush.

Other Brush Treatments

Between 1947 and 1956, Cook (1958) conducted a related study on brush removal and planting techniques. This study had two objectives: (1) to gain further understanding about the effectiveness of various brush removal methods, and (2) to understand more about the effectiveness of broadcast seeding on soils that are

rocky, steep, covered with small trees, or otherwise ill adapted to farm machinery. Cook concluded that the success of range reseeding operations is correlated with the method, season, and effectiveness of eradication and seeding following brush removal. Crested wheatgrass, when planted in the fall after plowing, produced the best stands over the 9-year study.

On experimental plots, sagebrush was removed by one of three methods: wheatland plow, Dixie log harrow, or railing. Treatments were applied in both the spring and fall. A whirlwind seeder was then used to broadcast the four grass species on experimental plots in both spring and fall.

Areas where plowing was used showed the least sagebrush reinvasion after 9 years—34 plants per 50-ft (15.2-m) transect line. All eradication methods seemed to be more effective in the fall than in the spring. For example, in the fall an average of 72 percent of the plants were eliminated under all treatments compared with 63 percent in the spring. In addition, a higher percentage increase of sagebrush occurred on areas treated in the spring over those areas treated in the fall.

Areas treated with the Dixie log harrow and then broadcast seeded supported the greatest number of seedlings after the first year, but over the entire 9-year study, the plowed areas produced more grass plants, and significantly more forage yield. By 1956, plowed areas were producing 183 lb/acre (205 kg/ha) compared to 110 lb/acre (123 kg/ha) for the harrowed areas—a difference of 60 percent.

Results for the four species of grass varied somewhat. Intermediate wheatgrass had the most plants on railed areas; the other species did best on plowed areas. Fall eradication of sagebrush and planting at the same season produced significantly higher numbers of seedlings of all four species than did spring treatments.

However, areas that were railed produced a greater number of seeded plants and more forage when this treatment was applied in the spring rather than in the fall. These results appeared to be related to the fact that sagebrush cover on spring-railed lands was only 49 percent compared to 83 percent on the fall-railed lands following treatment.

Broadcasting before sagebrush removal compared to seeding after removal produced a greater number of seedlings as well as a higher number of established plants and more forage of all species except crested wheatgrass. In this study, crested wheatgrass produced nearly the same results whether seeded before or after eradication of brush.

Differences in favor of broadcasting before sagebrush removal were less marked on plowed areas and were more marked when applied in spring than in fall. This finding may be due to vernalization of seed planted in the fall, whereas the seed planted in the spring lies exposed. Later studies investigate this contention.

Crested wheatgrass produced the highest number of seedlings per plot during the first growing season after treatments were applied. Intermediate wheatgrass produced the least. Yet, after 9 years, pubescent wheatgrass had a higher number of established plants per plot than

did the other grass species. Crested wheatgrass, because it produces a greater number of stems and leaves, produced more forage per acre than all other species even though this species had fewer total plants per plot. Tall wheatgrass, by contrast, produced the least amount of forage per acre and fewer established plants per plot.

Generally, then, Cook found crested wheatgrass and pubescent wheatgrass to be more adapted to broadcast seeding than were the other two species. Pubescent produced satisfactory stands under all methods during fall seeding but not in the spring. This finding held constant over the 9 years. Tall wheatgrass produced satisfactory stands when seeded in the fall and when broadcast before raiing in the spring. However, stands of tall wheatgrass became less vigorous over the years.

Seed Vernalization Studies

Early studies suggested certain grass species responded better to fall planting than to spring planting. As a followup, Frischknecht (1959) examined the effectiveness of vernalizing different species of grasses. He concluded that vernalization could be accomplished in some species of perennial grasses through fall field planting or storage of soaked seed in a snowbank or refrigerator prior to spring planting. Thus, when fall plantings are not feasible, vernalization of some species should help to obtain successful grass stands from spring planting.

Frischknecht began his research after he had observed that certain species, particularly mountain rye, intermediate wheatgrass, and mountain brome, merely put out short shoots when planted in the spring, but produced flower culms and seed the first year when planted in late fall even though the seedlings did not germinate until spring.

Frischknecht selected seeds from eight perennial grasses, soaked these seeds for 20 hours at room temperature, and then buried the seeds in a snowbank for 50 days prior to planting. The species studied were mountain rye, two varieties of intermediate wheatgrass, pubescent wheatgrass, crested wheatgrass, fairway wheatgrass, tall wheatgrass, and Russian wildrye. These seeds were then planted at Benmore. Although none of the grasses produced seed the first year, the treated seeds emerged a few days earlier than the untreated seeds and produced culms in the first year. Thus, vernalization seemed to be beneficial to some species, resulting in greater culm elongation and increased survival of seedlings.

This researcher then designed another study to further investigate the effects of vernalization on perennial species of grasses. Using only four species—intermediate and crested wheatgrass, Great Basin wildrye, and Indian ricegrass, Frischknecht exposed these seeds to four different treatments:

—20 hours soaking at room temperature followed by storing in a snowbank for 48 days near 32° F (0° C).

—20 hours of soaking as above, followed by 48 days of extremely cold storage in a locker at near 0° F (−18° C).

—36 hours of soaking at room temperature followed by 3 days in the cold locker.

—36 hours of soaking at room temperature, but no cold treatment whatsoever.

Seeds were then tested for viability in a germinator. Only Indian ricegrass failed to germinate. Yet, there were differences in the responses of other species based on the type of treatment. Locker storage at near 0° F seriously reduced germination of the two wheatgrass species but did not affect Great Basin wildrye. Frischknecht hypothesized that Great Basin wildrye might have been metabolizing less rapidly than the wheatgrasses when placed in the cold storage locker because it is normally the slowest species to germinate. In addition, seeds of the two wheatgrasses soaked for 36 hours appeared to be more susceptible to damage by subsequent cold storage at 0° F than seeds soaked for 20 hours.

Except for Indian ricegrass, all grass species from snowbank storage began to emerge within 20 days after planting in the field at Benmore. There were also differences between species according to treatment. With intermediate wheatgrass, for example, seeds from both the snowbank storage and 36 hours soaked without cold treatments exhibited about equivalent emergence rates. But, the second year in the field, only intermediate wheatgrass from snowbank storage showed good stands of grass, although a few plants of this species survived from other treatments (fig. 5). Only a few crested wheatgrass plants were surviving in the second year, but none from the 48-day locker treatment. Some plants of this species flowered the first year, regardless of treatment. Thus, in crested wheatgrass the evidence indicates that vernalization treatment is unnecessary for first-year flowering in contrast to requirements for intermediate wheatgrass.

Frischknecht then devised a study to investigate how snow bank storage followed by spring planting compared with fall planting and refrigerator and snowbank storage. In this study, four species of grasses were used: crested and intermediate wheatgrass, Great Basin wildrye, and Indian ricegrass. All four species were planted in the fall in moist soil. In the spring of the following year, similar plantings were made but in three combinations: untreated seeds, soaked and stored in snow for 60 days,



Figure 5.—Plants from vernalized seed (rear) show better survival and development at Benmore in the second growing season than do plants from untreated seed (foreground).

soaked and stored in a refrigerator for 60 days at 31° to 34° F (−0.5° to 1.1° C).

All treatments generally produced germination rates superior to those of untreated spring-planted seeds. Snowbank-stored seeds did a little better than the other treatments, but the differences were minor. Weather and soil conditions, of course, can exert a strong influence on these results at any time.

Although most species Frischknecht studied could produce flowers the first year with or without cold treatments, higher rates of flowering did result when seeds were treated before spring planting. Cold treatments appeared to hasten spring emergence and aided survival of seedlings on dry sites. Therefore, where fall plantings are not feasible, vernalization should help to obtain successful grass stands. Some seeds of intermediate wheatgrass remained vernalized for at least 1 year when dried and stored in a basement after removal from a snowbank (fig. 6). This procedure may produce a crop of seed from spring planting a year earlier than otherwise, or increase seed yields the following year.



Figure 6.—Culm production in intermediate wheatgrass resulted from snowbank storage of seeds prior to planting. Treatments were, from left to right: (1) snowbank storage for 67 days; (2) snowbank storage for 60 days, dried 7 days; (3) snowbank storage for 38 days, dried and stored in basement for 1 year; and (4) untreated seeds.

MANAGING SEEDED RANGELANDS

With its purchase in 1934 under the Central Utah Purchase Project, the Benmore area was typical of thousands of acres of abandoned farmland that was producing little or no forage. Because range management was still in its infancy, little was known about the best methods of restoring grazing capacity on these lands. But another area of equal interest was how seeded lands could be managed to maintain their productivity. Because spring is the critical time for most livestock operations, research at Benmore concentrated on furnishing appreciable amounts of spring forage for large numbers of livestock. Cattle and sheep often come through the winter in poor condition. With feed on winter ranges scarce and summer ranges not ready, some animals die and low calf and lamb crops result.

Good, high nutritive spring forage—an adjunct to larger calf and lamb crops as well as greater weaning weights—is often not available. Researchers hoped to ascertain the optimum level of grazing that would meet the animal's minimum requirements for growth and development and that also would maintain the vigor and productivity of the perennial grass stands.

The first seedlings at Benmore, as mentioned in the previous section, demonstrated that crested wheatgrass could provide early spring forage for livestock. But how would it respond to grazing? This and related questions were the object of much research conducted on the seeded pastures in Rush Valley.

Guidelines on Management

The seeded pastures at Benmore are some of the oldest in the Intermountain West. Based on research, such stands can be maintained indefinitely and can provide valuable forage for livestock during much of the year under proper management techniques. The following are management guidelines:

1. Crested wheatgrass can supply excellent spring forage nearly 2 weeks earlier than most native grasses and fill an important need in livestock operations.
2. Pastures seeded with crested wheatgrass or the other introduced grasses can increase grazing capacities up to tenfold over depleted sagebrush-grass range.
3. Crested wheatgrass also demonstrates excellent fall regrowth potential during favorable years. It can supply forage for livestock during fall if not grazed heavily in spring.
4. Seeded foothill ranges reduce the grazing pressure on adjacent depleted or deteriorating ranges and can delay and shorten the grazing season on high mountain ranges, allowing their improvement.
5. Rather than planting mixed introduced grasses, pure stands of these species appear best. Grasses can then be grazed in order of maturity during the season: crested wheatgrass in the early spring, followed by tall wheatgrass, then intermediate wheatgrass, and finally Russian wildrye. Pubescent wheatgrass was not preferred by animals under most conditions. Under conditions similar to Benmore—13 inches (33 cm) annual precipitation—tall and intermediate wheatgrasses cannot be counted upon to maintain good stands indefinitely.
6. A rotational grazing system is best with use pegged at 60 to 65 percent of current year's growth of crested wheatgrass. This level will produce the highest total animal gains and maintain the forage resource as well as minimize shrub invasion. This level of use will also leave enough forage for fall grazing and will limit the number of wolf plants.
7. Fat livestock should be sold after coming off the summer ranges and only the breeding herd and stockers retained into the fall.
8. Late summer and fall grazing are feasible on mature growth of crested wheatgrass, especially when a protein supplement is provided. Under these conditions, livestock gains are comparable to gains on forest mountain lands. If native wheatgrass ranges are available, livestock will make excellent gains on these lands during the fall.

9. Sheep do not use the introduced grasses over long periods as well as do cattle. Sheep tend to suffer weight losses during the fall, especially where sagebrush is dense. They can be expected to about maintain their weight on crested wheatgrass under a stocking rate of 50 sheep days per acre in the fall where sagebrush has a density of about 1.5 plants of all sizes per 100 ft² (9.3 m²).

Preliminary Studies

In 1943, the directors of the Benmore Experimental Range felt that the stands in some pastures were well established enough to permit limited fall grazing. To determine yields and grazing capacities, additional pastures were opened to both spring and fall grazing between 1944 and 1946. The first, rather limited study (Frischknecht and others, n.d.) sought to determine how crested wheatgrass should be managed for optimum production of forage and for sustained yields year after year. After 4 years, researchers found the following:

1. Crested wheatgrass was ready for grazing about 2 to 3 weeks earlier than native ranges.
2. Approximately 2.5 acres (1 ha) of crested wheatgrass would support one animal unit month (AUM), whereas 12 to 25 acres (4.9 to 10.1 ha) of depleted native range were necessary to support the same amount. Thus, planting crested wheatgrass on abandoned dryland farms could increase grazing capacities 10 times.
3. Gains per cow on the seeded pastures averaged 3 lb/day (1.4 kg/day) whereas cows gained only about half that much on depleted ranges.
4. Cattle that grazed on seeded pastures in the spring went onto summer ranges in excellent condition, whereas cattle that grazed on depleted native ranges went onto summer ranges in poor condition.
5. This increased grazing capacity on seeded spring ranges allowed resource managers to reduce grazing on depleted native ranges. With this reduction in grazing pressure, depleted native ranges began to show signs of recovery.
6. Crested wheatgrass also demonstrated a marked capacity for fall regrowth when rainfall was sufficient. Thus, its early readiness and fall regrowth potential allowed managers to shorten the season on summer ranges by as much as 2 months during most years.

Hence, grazing pressure on mountain ranges was reduced and they too began to show signs of recovery.

7. The uniform breeding season for cattle on seeded ranges resulted in a 95 percent calf crop (fig. 7), compared to about 70 percent on unseeded ranges where bulls and cows were run together the entire grazing season. Most research indicates that breeding of yearling heifers is not a good practice and usually does not result in a higher calf crop.

8. Calves were generally in excellent condition on seeded ranges at weaning time and thus commanded top prices over calves grazed on adjacent native ranges.

These findings meant that real long-range economic gains were possible if depleted ranges were cleared and seeded to crested wheatgrass. However, this first study, was far from systematic or of sufficient duration to be reliable. In addition, there were still many questions: What levels of grazing should be maintained? How long can cattle be held on these seeded ranges before the nutritive value of the grass declines? What type of grazing system, if any, should be used? Obviously, more studies were needed.

Systems and Intensities of Grazing

In 1947, the cooperating agencies at Benmore initiated an 11-year study to determine the proper grazing of seeded rangelands (Frischknecht and Harris 1968). After some preliminary measurements, researchers began to test 12 combinations of methods of spring grazing. The methods combined four systems and three intensities of grazing:

Systems of grazing

1. **Rotation.** Each 100-acre (40.5-ha) pasture was divided into three units with the cattle shifted between them in regular order periodically. Each subunit was grazed twice during the 60-day spring grazing season (April 20-June 20).
2. **Continuous.** Pastures were grazed continuously for the 60-day grazing (April 20-June 20).
3. **Delayed.** Beginning of a 50-day grazing was delayed 10 days (May 1-June 20).
4. **Shortened.** Grazing terminated early after 50 days (April 20-June 10).



Figure 7.—Cows grazed on crested wheatgrass produce good calf crops and high weight gains.

Intensities of grazing

1. **Light:** grass use about 50 percent.
2. **Moderate:** use about 65 percent.
3. **Heavy:** use about 80 percent.

After monitoring these systems for 9 years, researchers reported that intensity of grazing appeared to exert a greater influence on vegetal changes than did the various seasonal systems of grazing. Hence, the researchers recommended that range managers closely monitor levels of use if grass stands are to remain productive. Frischknecht and Harris (1968) also concurred with the earlier Benmore results that recognized that crested wheatgrass could fill an important forage need for livestock in the early spring (April 20) to early summer (June 20). Crested wheatgrass was ready earlier than native ranges and was also highly nutritious during this period. Overall, this study determined that crested wheatgrass, when grazed at approximately 65 percent use, resulted in good cattle gains and healthy grass production.

Systems of grazing.—On the basis of this 11-year study, Frischknecht and Harris (1968) observed that delaying the start of the spring grazing system by 10 days contributed to maximum grass yields and increased the basal area of plants. On the other hand, shortening the end of the grazing season by 10 days contributed to increasing plant numbers. The researchers also reported that a good rule of thumb is to not graze the same area at the same time of the growing season each year. Resting the range periodically from spring grazing will improve the overall long-range vigor of the grass plants.

Frischknecht and Harris also found that the largest number of plants were present in pastures where rotation or shortened grazing was practiced. The fewest plants occurred where grazing was delayed 10 days in the early spring. In addition, rotational grazing or delayed grazing coupled with heavy levels of use maintained grass stands better than did the same level of use with continuous or shortened systems of grazing. However, the researchers did not find any significant differences in levels of digestible energy between the four systems of grazing. Rotational grazing did prove to be the best overall method of grazing cattle when all factors were taken into account (fig. 8).

Intensity of grazing.—Originally, the intention was to graze all pastures in both the spring and fall, but heavy levels of use left nothing for the fall and thus fall grazing was discontinued on all pastures. However, it was believed that pastures grazed at the light and moderate levels in the spring could be grazed again in the fall, given sufficient late-season precipitation. The results seem to substantiate this belief.

The lightest spring grazing left enough forage so that fall grazing was feasible on all pastures. Even at 65 percent use, enough forage remained for limited fall grazing. But at the heavy levels, little remained by fall and regrowth was not substantial (fig. 9).

In the pastures grazed at light intensities, a large number of wolf plants developed. Cows tended to avoid these plants year after year, unwilling to graze between



Figure 8.—Cows were moved to a moderately grazed pasture that is delimited by a two-wire electric fence.

dried stalks to get new growth. When subjected to heavy grazing, these plants were soon used, and under moderate grazing there was a gradual reduction in old growth plants.

Moreover, the greatest number of young plants occurred in lightly grazed pastures, whereas the fewest were in heavily grazed pastures. Researchers attributed this difference to reduced seed production in heavily grazed pastures, although the importance of seed production has not been demonstrated.

Heavily grazed pastures showed reduced grass yields while the other two treatments over time differed little in herbage production. Heavily grazed units exhibited more numerous and larger dead plant centers than the other treatments. Yet, when averaged over 11 years, heavy grazing produced more digestible energy than the light and only slightly less than the moderate treatments. This finding agrees with other studies that concluded that frequently clipped crested wheatgrass maintains a higher overall nutritive value than unclipped plants, in large part because of new growth shoots. Moreover, removal of 80 percent of the current year's growth year after year resulted in: (1) a decline in herbage production; (2) accelerated dying of grass plant centers; (3) little or no seed production; (4) excessive trampling of both soil and grass, which increased soil erosion and broke up plant crowns; (5) accelerated invasion of rubber rabbitbrush and big sagebrush; (6) heavier use of forage by rabbits because of the presence of brush cover; (7) invasion of annual weeds, cheatgrass, Russian thistle, and halogeton; and (8) no fall grazing except in years of abundant regrowth (that is, with high precipitation).

Finally, cattle days per acre, as expected, were highest for the heaviest intensity of use, but the carrying capacity per acre dropped considerably when compared to capacities for the light and medium intensities.



(A)



(B)



(C)

Figure 9.—(A) Lightly grazed pasture shows differential grazing and accumulation of old growth as a result of some plants being ungrazed each year. (B) Moderately grazed pasture shows fairly uniform use. (C) Wire cage protection plot covers an area slightly larger than 9.6 ft (0.9 m) in heavily grazed pasture.

Animal gains.—The results of the 12 combinations of grazing showed that rotational treatment produced the highest gains per acre during 7 of the 11 years, but the least on a daily basis. The reason for this difference is not clear, but researchers suggested that the short-term results may be related to the quality and quantity of forage at any one time. The system that removed cattle 10 days early from seeded pastures produced the lowest gains per acre in 7 of the 11 years of the study. However, because growth is most nutritious earlier, this system produced the highest daily gains over the 11 years.

Harris and others (1957) observed that the greatest gains for cattle occurred in the early spring and then decreased as crested wheatgrass matured. This finding is consistent with other studies showing that the nutritive value of crested wheatgrass and its palatability decline with seasonal maturity. By the first of July, cellulose and lignin levels are comparatively high, while protein and phosphorus are low.

Gains per acre were also dependent on the type of grazing system used and the grazing intensity, as shown in this summary:

System	Gains in lb/acre (kg/ha)
Rotation	42.9 (48.1)
Delayed 10 days	40.6 (45.6)
Continuous	39.0 (43.7)
Removed 10 days	37.3 (41.8)
Intensity	
Light	36.8 (41.2)
Moderate	43.4 (48.6)
Heavy	39.7 (44.5)

While daily gains of individual animals were lowest for heavy grazing, total gains per acre were highest for this intensity for the first 2 years of study. But this level of use proved the most detrimental to the forage. After 6 years, the gains for animals on the heavy use pastures declined to levels below those for animals grazed at light use. Forage production was seriously impaired by heavy use year after year and resulted in the least gains per acre by the end of the study. This situation was a primary factor leading to the original deterioration of western rangelands. Incorrect season of use was also a factor.

All systems of grazing resulted in sufficient gains for beef production when used at 65 percent. But, during the spring, grazing should be somewhat less than this level for lactating cows. Cows that calved on lightly grazed units entered summer ranges 30 lb (13.6 kg) heavier than cows calving on moderately grazed units, and 73 lb (33.1 kg) heavier than those on heavily grazed units.

Generally, daily weight gains by cattle were influenced by the quantity and quality of forage, which fluctuated with levels of precipitation. Peak gains were measured in years when rainfall was high and forage production was at its maximum. Conversely, animal gains declined when the amount of available forage was reduced. Lactating cows gained less throughout the study on the moderately grazed pastures as compared to the lightly

grazed pastures. All other classes of cattle gained as well on moderately grazed pastures as those lightly grazed. Average daily gains for five classes of cattle over all treatments were:

	Lb/day (kg/day)
Dry cows and steers	3.06 (3.43)
Pregnant cows	3.03 (3.40)
Lactating cows	2.49 (2.79)
Yearlings	2.47 (2.77)
Calves	1.77 (1.98)

Because cattle are generally fat after grazing on mountain ranges during the summer, and lower gains are expected on fall ranges, these researchers recommended that owners sell some livestock when they come off the summer ranges and use the crested wheatgrass pastures only for the breeding herd or stockers.

Forage yields.—During the 11-year study at Benmore, grass yields fluctuated with precipitation levels. However, differences in grass yields between the four systems of grazing were not statistically significant. Overall, grass yields were better maintained under the rotation and the delayed-10-days systems than under the other two.

Crested wheatgrass became dry during the hot summer months. Although western wheatgrass comprised only a minor amount of the total forage, it increased during the study period and was found to be a valuable complement to crested wheatgrass. Cattle grazed western wheatgrass in late spring after the crested had been well used. They also readily grazed it in the fall. Rhizomatous western wheatgrass also provided a much more uniform ground cover than crested and was superior for controlling soil erosion where it occurred.

Bulbous bluegrass also increased during the study, but it adversely affected crested wheatgrass production. Most bulbous bluegrass plants were within or close to crested wheatgrass crowns and used soil moisture earlier. In addition, bulbous bluegrass growth is short and dries early. The researchers noted that this species provided little forage for cattle under conditions at Benmore.

Frischknecht and Harris (1968) concluded that crested wheatgrass was an excellent source of livestock forage. It can furnish about 60 to 70 days of spring grazing and, with adequate early fall rains, 40 to 50 days of fall grazing, thus expanding the productive capacity of spring-fall ranges and easing the burden on limited summer ranges. Moreover, livestock will generally gain 40 to 50 lb of beef on each acre (44.8 to 56.0 kg/ha) of crested wheatgrass during the spring season if rotational grazing is practiced at about the 65 percent use level. These cattle then go onto summer ranges in excellent condition and the vigor of the forage is maintained.

An example of the value of green regrowth of crested wheatgrass for fall grazing in certain years was reported by Keck and Frischknecht (1968). Calves came off the mountain summer range with their mothers and remained with them on crested wheatgrass until they were sold 40 days later. During the time, the calves gained an average of 65 to 70 lb (29.4 to 31.7 kg) per head and some individual calves gained up to 90 lb (40.8 kg).

Nutrient Content and Palatability

After the 11-year pasture study the challenge was to find ways of integrating grazing of introduced grasses with native species, especially during the summer and fall. As plant growth advances, total protein in these grasses declines and amounts of cellulose and lignin increase (Cook and Stoddart 1961). Of the four introduced wheatgrasses tested, tall and intermediate wheatgrasses matured later and had lower levels of cellulose and lignin than did crested or pubescent wheatgrasses in midsummer. In fact, by the second or third week of June, the nutritive value of crested wheatgrass is below that required for lactating animals (Cook 1956). Therefore, researchers began to look at the native sagebrush-grass ranges as auxiliaries to grazing seeded pastures.

Cook and Harris (1952) reported that while cheatgrass is rather abundant, it remains green only a relatively short time and becomes unpalatable to livestock after maturity. Cook and Stoddart (1950) found that bulbous bluegrass and common winter rye (an annual) were also inadequate auxiliaries for range forage. Both species were uneconomical to establish and forage yields were much too low to be satisfactory. Planting perennial grass seed with common winter rye is also not recommended. Rye tends to compete with perennial grass seedlings for moisture and actually retards the final establishment of grass from 1 to 3 years (Benmore Field Day Report 1949, unpublished).

While healthy native sagebrush-grass ranges can be used satisfactorily from about May 1 to June 10, at other times they cease to meet the minimum nutrient requirements for lactating animals. Restoration of spring-fall ranges by seeding can meet a large part of these requirements. Cook (1966a) noted that approximately 35 lb (15.9 kg) air-dry herbage per day were necessary to sustain a cow and her calf. This amount includes forage lost by trampling, insect damage, rodents, and rabbits.¹ During early spring, cattle grazed on native sagebrush-grass ranges do less well than livestock on seeded ranges. Cows on the smaller Benmore pastures gained an average of 1.6 lb (0.7 kg) per day while cows on native ranges gained only 1 lb (0.4 kg) per day. Highest gains were made on intermediate and tall wheatgrass, both of which mature later than crested or pubescent wheatgrasses. Both intermediate and tall wheatgrass also meet the requirements of lactating animals better than the other two species because their protein and energy levels remain higher much longer

¹Grasshoppers and rabbits, when numbers are at their peaks, do tremendous damage to grass plants, especially to new seedlings. Management provision should be made to control their effects on stands. Research shows that only 20 grasshoppers per square yard on an acre (24 grasshoppers/m² on 0.4 ha) of range consume as much as a 1,000-lb (453.6-kg) steer (personal communications with Austin Haws, Utah State University). A series of exclosures on various wheatgrass stands show that both rabbits and livestock prefer intermediate wheatgrass to the other three species. On rabbit-fenced plots, an average of 796 lb per acre (892.2 kg/ha) were produced by all species. On unprotected areas, only about 531 lb per acre (595.2 kg/ha) were produced. Rabbits annually consumed about 33 percent of the forage—no minor consideration.

into the growing season. Crested and pubescent wheatgrasses also were lacking in phosphorus in the later season, but this deficiency was corrected by adding monosodium phosphate to the stock water.

When Cook grazed cows on pastures of Russian wildrye, he found that lactating cows did well. Livestock gained an average of 3.2 lb (1.4 kg) per day on this species, but only 2.8 lb (1.3 kg) per day on crested or pubescent wheatgrass. Yet, as already noted, Russian wildrye is difficult to establish and is not a heavy forage producer.

Once livestock were moved to mountain ranges, all livestock made similar gains regardless of previous treatment. However, native ranges may not provide sufficient nutrient levels, especially during lactation. Supplementation may be required. To answer one of the questions raised by Cook's study, Mitchell (1969) investigated the possible chemical differences in grasses at different times of the season. At first, Mitchell found no significant differences in the chemical composition of forage simultaneously collected in early spring from relatively pure, open stands of different grass species. But samples collected at different times during the grazing season showed apparent differences.

Russian wildrye, for example, had a total protein level that was higher than crested or intermediate wheatgrass during all collection times. However, crested wheatgrass was higher in protein in the early spring, but intermediate wheatgrass was higher later in the season. By July 1, Russian wildrye was lacking in phosphorus content, and Mitchell generally found that it responded to variations in climate much more radically than the other species. Even after maturity, Russian wildrye remains high in protein and can produce weight gains in livestock, usually until the seed shatters. Afterwards, animal weight losses may occur because digestible energy may be lacking.

Like Cook, Mitchell observed that although Russian wildrye had seeming advantages over the wheatgrass species, this species should not be solely relied upon because of its weightier disadvantages. Based on the Benmore experience, Cook (1966a) concluded that crested wheatgrass stands could be maintained indefinitely if not grazed at more than 55 to 60 percent use and if brush control were administered periodically. In addition, wolf plants could be adequately controlled by grazing every 3 or 4 weeks at a rate of 0.5 to 1.0 acre (0.2 to 0.4 ha) per cow for a few weeks in early spring after new growth has reached about 3 inches (7.6 cm). Excellent weight gains would thus result and the vigor of the grass stand maintained perpetually.

Because the numbers of cattle being permitted on high mountain ranges have been reduced in some areas, researchers began to look at whether crested wheatgrass pastures could be grazed all summer without producing harmful effects to livestock. Cook (1966a) and Vallentine (1959) concluded that pastures of seeded wheatgrass were far from adequate for season-long grazing. While animals could be rotated from one pure stand to another as the different species matured, the pastures were good only to midsummer and then livestock must be moved to summer ranges in the mountains. Research

indicated that if the forage is inadequate nutritionally, cows rob their own bodies to feed the calves.

Protein Supplement in Summer

To investigate the feasibility of summer grazing on the Benmore crested wheatgrass pastures, Harris and others (1965) conducted a study between 1961 and 1963. Cows and calves were grazed during six consecutive periods from April 20 to December 15. Some cows received protein supplements of 0.75 lb (0.3 kg) per head per day (fig. 10).



Figure 10.—Cows at Benmore eat protein supplement from a wooden manger.

Researchers found that yearlings did not get as much of the supplement as older stock because they were pushed away. Still, yearlings made weight gains as the season progressed until early fall. Even after this date, losses were still slight. In the end, there were no significant differences in the final weights of the yearlings between the supplemented and the nonsupplemented treatments. Calves also showed no significant response to the supplement. Cows with the supplement finished the season 50 lb (22.7 kg) heavier than the non-supplemented cows. Younger animals gained an average of 250 lb (113.4 kg) over the season. Moreover, gains of livestock grazed on forest lands during the summer did not differ markedly from gains of supplemented cows on Benmore pastures.

Therefore, where no alternative for summer and fall grazing exists, cows can be maintained with a supplement on crested wheatgrass and make gains comparable to livestock grazed on mountain ranges. In addition, a suitable feeder calf can be produced on such mature pastures. Yearlings, too, can make reasonable gains. These researchers concluded that when properly managed, crested wheatgrass will supply grazing from late April through mid-December.

A similar study reported by Harris and others (1968) reached many of the same conclusions. The study sought to determine if cattle grazing pure stands of crested wheatgrass at different seasons could gain weight either with or without a protein supplement. Yearlings and cow-calf pairs were distributed between a number of

pastures with the following treatments: early spring plus early fall grazing of crested wheatgrass, late spring, all spring, early summer, late summer, early fall, and late fall. For comparison, part of the animals were moved to an adjacent mountain range in the summer to assess gains on higher native ranges compared to gains on crested wheatgrass pastures. Fluctuations in yearly precipitation occurred during the 4 years of this study, resulting in variations in gains during the different grazing seasons. Nevertheless, some interesting findings resulted. Yearlings and calves showed no significant differences between the supplemented, nonsupplemented, or forest-grazed treatments. (Cows pushed yearlings away from the supplement, which may explain why the yearlings showed no response.) The calves gained consistently through all periods of grazing, averaging about 400 lb (181.4 kg) by the time they were sold, a gain of 250 lb (113 kg). The yearlings also finished the season with a gain in weight regardless of treatment, averaging 224 lb (102 kg) gain after losing slightly in the fall.

Cows responded positively to the supplement, ending the entire season with an average gain of 125 lb (57 kg) compared to only 50 lb (23 kg) for nonsupplemented cows. Furthermore, there were few significant differences in gains between cows grazed on mountain range in the summer and cows grazed on crested wheatgrass pastures with a protein supplement in the summer.

As expected, the highest gains per acre for all animals were in early spring and during the all-spring grazing treatments. But this study also demonstrated that livestock could be grazed from April to October on stands of crested wheatgrass and still make significant gains in weight. Hence, crested wheatgrass pastures may provide a viable alternative to higher summer ranges.

Integrating Crested Wheatgrass and Native Ranges

To further test grazing mature crested wheatgrass, Kearl and others (1971) experimented with the following grazing combinations involving 192 cows with calves:

1. Crested wheatgrass in the spring, summer, and fall. Summer grazing involved regrowth of crested wheatgrass in pastures grazed in early spring but rested in late spring.
2. Same as No. 1 except cows received supplement in summer and fall.
3. Crested wheatgrass in the spring, forest in the summer, and back to the crested wheatgrass in fall. Fall grazing involved mature growth of crested wheatgrass.
4. Same as No. 3 except cows received supplement in fall.
5. Crested wheatgrass in early spring, native range in late spring and fall, and forest range in the summer.

The purposes of this study were (1) to work out a viable system of grazing crested wheatgrass in conjunction with adjacent native range and higher summer range from mid-April to mid-December, and (2) to compare the merits of a protein supplement for cattle

grazing on crested wheatgrass during the summer and fall when combined with spring grazing. Supplemented animals received the equivalent of 0.75 lb (0.34 kg) of supplement containing 35.6 percent protein and 2.3 percent phosphorus daily in three feedings per week. This study also compared biuret and cottonseed meal as protein supplements for cattle on crested wheatgrass.

Researchers found that cows all gained about the same during early and late spring, regardless of treatment (fig. 11). During summer little difference existed in gains between supplemented and nonsupplemented cows while grazing regrowth of crested wheatgrass that remained green into summer. Again, both of these groups also compared favorably with cows grazing forest ranges in summer. The biggest differences in weights between treatment groups occurred during the early and midfall, a period when mature crested wheatgrass is low in nutrients. All cows grazing crested wheatgrass showed losses in weight during the early fall, whereas those grazing adjacent native ranges gained weight during this period (fig. 11).

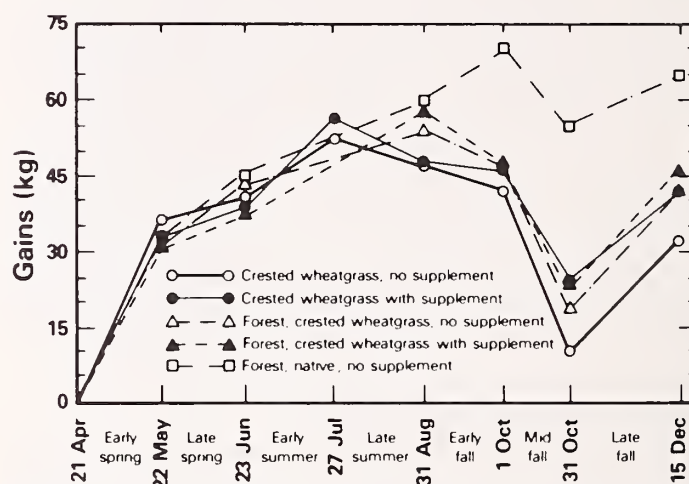


Figure 11.—Accumulative gains of cows on five grazing systems (see Kearl and others 1971).

The beneficial effects of the supplements were evident in early and midfall on crested wheatgrass not previously grazed in spring. These effects also carried over to the end of late fall (December 15) after all animals were grazed together on native range for 45 days without the supplement. In addition, cows that grazed crested wheatgrass season long but received supplement in summer and fall finished the entire season 22 lb (10 kg) heavier than similar cows that had not received the supplements. Cows supplemented on crested wheatgrass in the fall after grazing on forest lands in the summer finished the entire season 11 lb (5 kg) heavier than their nonsupplemented counterparts. Cows grazing the native ranges after coming off the forest mountain ranges finished the season 44 to 66 lb (20 to 30 kg) heavier than supplemented and nonsupplemented cows, respectively, grazing on crested wheatgrass for the entire period.

Calves also made excellent gains throughout the study. However, average daily gains were reduced slightly during midfall (October 31) when forage was dry and stemmy. Although none of the calves were supplemented, those on crested wheatgrass pastures all season long averaged 280 lb (127 kg) accumulative gains since late April, regardless of whether the mothers were supplemented or not. However, after coming off forest lands, calves on crested wheatgrass averaged 291 lb (132 kg) accumulative gain since going on pasture in late April. Calves on native grass pastures after coming off forest lands averaged 300 lb (136 kg) accumulative gain since April. Thus, calf gains followed somewhat those of the cows.

All differences in animal gains on crested wheatgrass in the fall were positive in favor of supplementation of some kind. Moreover, cattle gains tended to favor biuret over cottonseed meal. On the basis of this study, greatest gains in animal weight occurred with treatment No. 5 where cows and calves were grazed on crested wheatgrass in early spring, adjacent native range in late spring, forest mountain lands in the summer, and native foothill range again in fall. This combination appeared to be the most beneficial for both livestock and grass. Weight gains for these animals surpassed those supplemented on crested wheatgrass, yet the differences were small in some cases. Little difference was noted in gains between supplemented and nonsupplemented cows that grazed crested wheatgrass regrowth in the summer. Left still undetermined was whether these differences in cow weights among the five treatments at the end of the season carried over from year to year in breeding performance.

Frischknecht (1978b) concluded that improved native range, where the most prominent grasses are thickspike and bluebunch wheatgrasses, can be used for grazing in the late season in combination with crested wheatgrass pastures that are grazed in early spring. Depleted native range was improved by rest from grazing during the spring growing period, coupled with periodic sagebrush control. This combination restored these areas to a productive status equal to seeded crested wheatgrass range, which was 2.5 acres (1 ha) per AUM. Some rotation between seeded and native range is recommended so livestock do not graze the same range at the same time each year.

Sheep Grazing Studies

Studies were also conducted at Benmore to examine management of sheep on seeded spring-fall ranges. Because introduced grass species had proven so valuable for cattle, would sheep also benefit from seeded pastures? Cook and Stoddart (1961) reported that sheep tended to be more selective of various plant parts and ate more leafy material and avoided dry or coarse portions. Hence, intake declined as the grazing season progressed. Ewes, for example, gained weight in early spring but tended to lose weight in late spring on both crested and tall wheatgrasses. However, late season gains were reported for sheep on intermediate wheatgrass. Like cattle, sheep did not make good use of the less palatable pubescent wheatgrass.

In another study, Frischknecht and Harris (1973) grazed cattle in early spring and sheep in early and late fall on three 100-acre (40.5-ha) pastures of crested wheatgrass that had different densities of sagebrush. One goal was to determine if sheep could help maintain grass productivity by controlling the spread of sagebrush on seeded ranges. These researchers found that on pastures stocked uniformly at 40 to 50 sheep days per acre, depending upon the year, weight gains and losses of sheep in fall were directly related to the amount of sagebrush in each unit. For the lightest density—1.5 plants per 100 ft² (9.3 m²)—sheep maintained their weight during the 5- to 6-week early fall season, but then lost an average of 3.5 lb (1.6 kg) per head in the 5- to 6-week late fall season. Where the density of the sagebrush was 3.5 plants per 100 ft², the sheep showed weight losses of 1.6 lb (0.7 kg) and 5.1 lb (2.3 kg) per head for the early and late fall periods, respectively. Greatest weight loss occurred on the pasture having 13 plants of sagebrush per 100 ft² (fig. 12), amounting to 3.5 lb (1.6 kg) per head in early fall plus an additional 8 lb (3.6 kg) per head in late fall. Overall, this study noted that sheep lose weight in cold weather and gain best when there is considerable green fall regrowth resulting from late summer and early fall storms.

In tests with cattle and sheep, Cook and Stoddart (1959) found that cattle made better use of seeded wheatgrass pastures than did sheep. Lactating cows continued to make gains throughout the spring season, while lactating ewes lost weight on some seeded species in the late spring season. This suggests that sheep may have to be supplemented or moved to summer ranges earlier purely for nutritional reasons. Cook also found that cattle could tolerate the summer heat longer than sheep on Benmore pastures, remaining on seeded pastures about 3 weeks later than sheep. However, ewes that grazed seeded pastures during spring produced about 20 lb (9.1 kg) more lamb at weaning than ewes that grazed the native sagebrush-grass pastures.



Figure 12.—Sheep lost weight when grazed on this range where sagebrush averaged 13 plants per 100 ft² (9.3 m²).

COMPETITIVE RELATIONS BETWEEN GRASSES AND SHRUBS

On most ranges in the Intermountain West, pure stands of grass are infrequent except following fire. Brush species gradually invade seeded pastures even if no grazing has occurred. Researchers at Benmore, investigating the nature of competitive relations between grass and shrubs, have focused on rate and nature of brush invasion, growth characteristics, livestock preferences, and long-term trends.

Guidelines on Competition

One aspect of spring-fall ranges that has not been well understood is the competitive relationship between grasses and shrubs. Studies at Benmore have resulted in the following guidelines on this competition:

1. Brush species such as sagebrush and rabbitbrush compete with perennial grasses on western rangelands. Big sagebrush is a far more serious competitor with grass species than rubber rabbitbrush because of its lateral root system and growth cycle.
2. Taller brush species trap drifting snow, resulting in increased soil moisture in the immediate vicinity of brush plants.
3. Brush species can reinvade even the most vigorous foothill grass stands in certain years when moisture is above average regardless of whether or not grazing has been allowed. Periodic brush control will be required to maintain vigor of grass in competition with sagebrush.
4. To a limited extent, grass species can inhibit brush development, especially the roots if the grass plants are well established and vigorous.

Studies on Relations Between the Species

In the early years of their long-term grazing study on crested wheatgrass, Frischknecht and others (1953) recognized that big sagebrush and rubber rabbitbrush invaded most readily where there was less than a full stand of grass and in some heavily grazed spots. In the latter instances, young brush plants were commonly found in the dead centers or near the edge of severely weakened grass plants where the microenvironment was apparently most favorable. A few years passed before pastures as a whole showed increased brush invasion with increased intensity of grazing.

Frischknecht and Harris (1968) reported that sagebrush and rabbitbrush invaded most rapidly where grazing had been the heaviest. The invasion of these species into grass stands was also hastened by wet spring seasons following relatively dry years. In fact, both brush species have been found to invade so-called "slik" spots in wet years that are otherwise resistant to their invasion. Even so, because of the high concentration of salts in "slik" soils, the growth of these plants is slow, and they seem to be stunted and short-lived.

Cook (1966a) found that brush species will reinvade most seeded foothill ranges even if grazed only lightly. On sample plots, this researcher determined that 71 percent of the reinvading sagebrush was reestablished

just 2 years after removal of the original stands. Big rabbitbrush reinvaded at a more moderate rate.

In a more detailed study, Cook and others (1967) noted that brush species—notably sagebrush and big rabbitbrush—invaded seeded pastures within the first 6 years after planting. The invasion of rabbitbrush was inversely related to grass density—good stands of grass restrict the rate of invasion. Sagebrush, however, tends to be more competitive and can invade more easily. For example, Cook and Stoddart (1951) reported that perennial grasses seeded into dense stands of sagebrush or cheatgrass rarely become established. Frischknecht (1978a) concurred with this finding, reporting that solid stands of sagebrush have developed on abandoned farmland and formed communities closed to grass seedling establishment. He also found (1962) that at Benmore young sagebrush plants invaded established stands of crested wheatgrass downwind from parent sagebrush plants. Ninety percent of sagebrush progeny were found within 30 ft (9 m) of parent plants (fig. 13). Some form of brush control is absolutely required to maintain grass productivity.



Figure 13.—Young sagebrush plants invade crested wheatgrass stands downwind of parent sagebrush. Rapid invasion occurs where parent plants are spaced about 30 ft (9 m) apart.

Frischknecht and Harris (1973) subsequently reported that, once established, sagebrush competes successfully with perennial grasses and in time tends to become dominant on spring-fall ranges. In years with above-normal spring precipitation, sagebrush seedlings were often able to invade even the most vigorous grass stands. Thereafter, these brush plants compete with grasses for moisture in the same rooting depths. In addition, sagebrush has the advantage of trapping snow around its base, which also improves its total soil moisture potential in the spring (fig. 14). Further, spring cattle grazing provides an additional competitive edge to sagebrush by weakening grass species at a time when the growth cycles of sagebrush and grasses coincide. Therefore, soil moisture not used by grass plants is made available



Figure 14.—Ungrazed grass plants as well as sagebrush and rabbitbrush cause snow to accumulate in drifts. This increases the soil moisture for these plants.

to sagebrush, which flourishes and gradually becomes more vigorous each year. Because the growth cycle of rabbitbrush begins later in the season, it probably does not inhibit the vigor of grass plants.

From a 3-year study of competitive relations on caged plots on grazed range, Frischknecht (1963) noted differences between rubber rabbitbrush and big sagebrush. Up to this time, researchers generally agreed that sagebrush provided stiff competition for grasses (Blaisdell 1949), but the documentation on rabbitbrush was less complete. In addition, more research was needed to determine why sagebrush was such a vigorous competitor with perennial grasses.

Frischknecht found that grasses and rabbitbrush appeared to carry on a mutually beneficial relationship. Crested wheatgrass grew more rapidly in the early spring underneath rabbitbrush plants. This grass was 4 to 6 inches (10 to 15 cm) taller than grasses in the open, but it was not preferred by cattle in the early spring even when the brush seemingly offered no real obstacle to grazing. However, crested wheatgrass under rabbitbrush plants remained more succulent and was subsequently favored by livestock in the fall. Even fall regrowth on crested wheatgrass plants under rabbitbrush was more lush than grass plants in the open or under sagebrush plants. Frischknecht concluded that the presence of rabbitbrush increased the value of grass for fall grazing (fig. 15).

With respect to sagebrush-grass relations, Frischknecht again found that spring grazing increased the competitive advantage of sagebrush (fig. 16). Conversely, crested wheatgrass appeared to have a competitive edge over rabbitbrush in both time of growth and type of root system. Crested wheatgrass seemed to inhibit the growth of rabbitbrush more so than rabbitbrush inhibited the growth of crested wheatgrass (also see McKell and Chilcote 1957).

A comparison of the root systems of both sagebrush and rabbitbrush by Frischknecht revealed that sagebrush



(A)



(B)

Figure 15.—(A) Crested wheatgrass shows high production under rabbitbrush prior to fall grazing. (B) The same location shows close use of grass under rabbitbrush after fall grazing by cattle.



Figure 16.—Barren areas tend to develop around sagebrush, in contrast to high production of grass under rabbitbrush.

not only had a taproot but highly developed lateral roots in the surface soils—that area where grass roots are also most numerous (fig. 17). Thus, they compete for the same soil moisture. Rabbitbrush, by contrast, tended to have a deeper taproot and less developed lateral roots. Considering the different growing cycles, time of season, and soil depth, soil moisture was used differentially by rabbitbrush and grass. Frischknecht therefore concluded there was little basis to justify control efforts on rubber rabbitbrush at Benmore, particularly where fall grazing was practiced.

During the early 1960's several researchers looked more closely at the competitive relations between these plants. Leonard (1964), for example, looked into competition for available soil moisture on Benmore's ungrazed areas. Soil moisture was significantly greater under rabbitbrush compared to crested wheatgrass plants during all test dates throughout the summer. These differences were more pronounced at 12 inches (30.5 cm) than at 18 inches (45.7 cm) deep.

However, Leonard found no significant differences in soil temperature between grass and brush. But soil moisture and soil temperature were found to be inversely related to time—the later the season, the higher the soil temperature and the lower the soil moisture.

Interestingly enough, on ungrazed range Leonard did find a significant decrease in air-dry herbage production for crested and tall wheatgrass because of the presence of rabbitbrush. These findings are somewhat different from Frischknecht's 1963 results on grazed range. Intermediate wheatgrass, however, seemed relatively unaffected by rabbitbrush plants. Cook and others (1965) pointed out that Frischknecht may have minimized, to too great a degree, the effects of rabbitbrush crown cover. These researchers reported that production was better for crested and tall wheatgrass plants within 36 inches (91.4 cm) of rabbitbrush plants compared to those within 10 inches (25.4 cm). These plants produced an average of 0.7 ounces (20 g) more forage, had a greater basal diameter, and produced more seed heads per plant. In addition, Cook and others (1965) reported that rabbitbrush used soil moisture more slowly than grass, but it still used moisture that would have otherwise been available to the grasses. They concluded that the grass growing underneath rabbitbrush plants appeared taller and more succulent because livestock merely grazed more accessible forage first. Only when most forage had been depleted, usually in the fall when good forage is scarce anyway, would cattle then graze grasses among the branches of rabbitbrush. These researchers said rabbitbrush was competing to the detriment of perennial grass species.

Leonard (1964) found additional evidence that rabbitbrush deters grass production. While no significant difference was noted in basal diameter in the presence or absence of rabbitbrush, the number of grass seed heads was significantly reduced, which was noted also by Frischknecht (1963). This latter difference was more pronounced for crested than for tall wheatgrass. Leaf length was apparently unaffected by the presence of rabbitbrush.

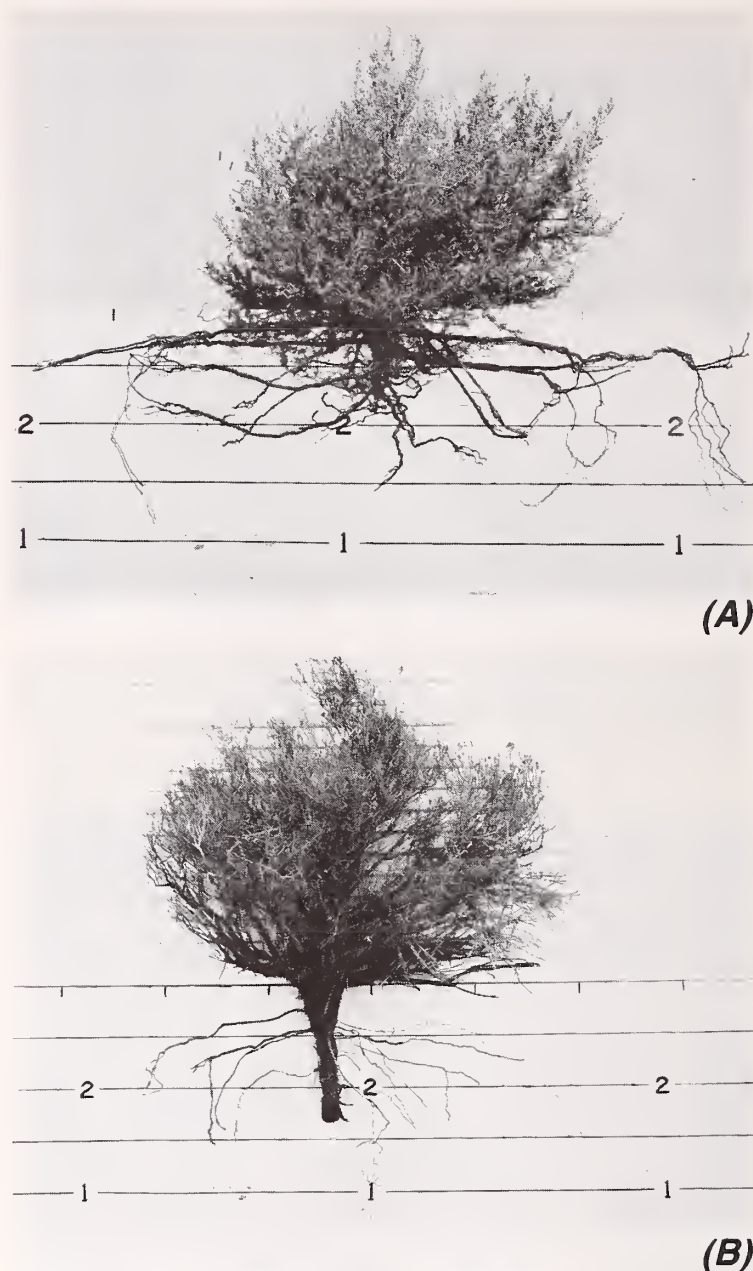


Figure 17.—(A) Lateral roots of big sagebrush provide keen competition to grass. (B) Rubber rabbitbrush growing near the same big sagebrush has prominent taproot, but lesser lateral root system.

Furthermore, Leonard noted that air-dry production was slightly greater for both crested and tall wheatgrass when growing in the absence of brush, nor did the grass apparently inhibit brush growth. Neither the height nor the base of brush species was affected by the presence or absence of wheatgrass plants. Yet, the presence of wheatgrass species did influence the development of lateral roots of brush—crested wheatgrass more so than tall wheatgrass. Leonard found fewer roots on the side of where wheatgrass plants were present. Root density was also less as a result of close wheatgrass plants. Still, root depth or penetration of the clay hardpan was unaffected by the presence or absence of wheatgrass plants.

Overall, crested wheatgrass appeared to use soil moisture much more rapidly and completely than did rabbitbrush.

CONTROLLING BRUSH REINVASION

As the preceding studies show, brush species such as sagebrush and rabbitbrush can easily reinvade improved rangelands regardless of the method of control or system of grazing. In fact, in certain years these species have reinvaded vigorous grass stands where all grazing was excluded. Big sagebrush competes with the grasses, and heavy infestations may ultimately reduce potential grass yields by as much as 70 percent.

Benmore studies show that moderate grazing coupled with an initial effective method of brush removal can reduce reinvasion. Nevertheless, periodic treatments for controlling sagebrush on improved ranges must be practiced to maintain grass yields and must be recognized by range managers as a maintenance cost.

Guidelines on Control

Several chemical and biological methods to control reinvading big sagebrush were studied at Benmore. The following guidelines resulted from those studies:

1. Under satisfactory conditions of temperature, humidity, and wind, adequate herbicide kills of sagebrush can be obtained from aircraft applications up to 200 ft (61 m) height of flight.
2. Rate of application of 2,4-D herbicide results in significant differences in rabbitbrush mortality, with 3- and 4-lb/acre (3.4- and 4.5- kg/ha) rates the most effective.
3. To successfully kill rabbitbrush, 2,4-D should be applied when soil moisture is above 13 percent in early June, particularly at the 2-ft (0.6-m) level.
4. The best herbicide kills of both big sagebrush and rubber rabbitbrush are obtained with mixtures of Tordon 22-K, Esteron, and Kuron.
5. Of livestock, sheep are the most effective control agents studied at Benmore. Cattle offer no hope of control of brush species.
6. Using insects for biological management of spring-fall ranges is impractical and unpredictable.

Chemical Methods

Total protection from grazing does not stop shrub invasions and plowing destroys both brush and grass alike. Therefore, a major area of investigation has been the use of chemical herbicides and defoliant to eliminate brush from improved ranges. One of the most common herbicides used on ranges has been 2,4-D.

In May 1958, Cooperrider and Worf (unpublished report) conducted a study on two sections (1,280 acres or 518 ha) of sagebrush range south of the Benmore crested wheatgrass pastures to determine the maximum height from which herbicides could be effectively applied from fixed-wing aircraft. The study sought answers to problems encountered by the Forest Service (Region 4) during the previous 10 years when chemical herbicides were first used as range improvement tools. Information to that time indicated that best results for control of big sagebrush were obtained from applications of herbicides flown 25 ft (7.6 m) or less above ground level. However, terrain and obstacles such as trees or telephone

and power lines often made that height extremely hazardous for fixed-wing aircraft. Flights above this level also involved problems with herbicide drift and spotty applications.

Cooperrider and Worf designed a study to treat four large areas, each 0.5 by 1 mile (0.8 by 1.6 km) with a herbicide at the rate of 2 lb (0.9 kg) butyl ester in diesel oil at 3 gallons solution volume per acre (28.1 liters/ha). Heights of flight were 15, 50, 100, and 200 ft (4.6, 15.2, 30.5, and 61 m) above ground level using a World War II Navy Torpedo bomber flying at a constant groundspeed of 180 mi/h (289 km/h). An effort was made to apply the herbicide under uniform environmental conditions.

Cooperrider and Worf concluded that adequate kills of sagebrush could be obtained from fixed-wing aircraft flying 200 ft (61 m) above ground level if satisfactory conditions of temperature, humidity, and wind existed. They believed that weather factors were more critical than height of flight. Frischknecht (1978b) described the overall kill of sagebrush on this area and subsequent increase of new plants over a 12-year period (fig. 18).

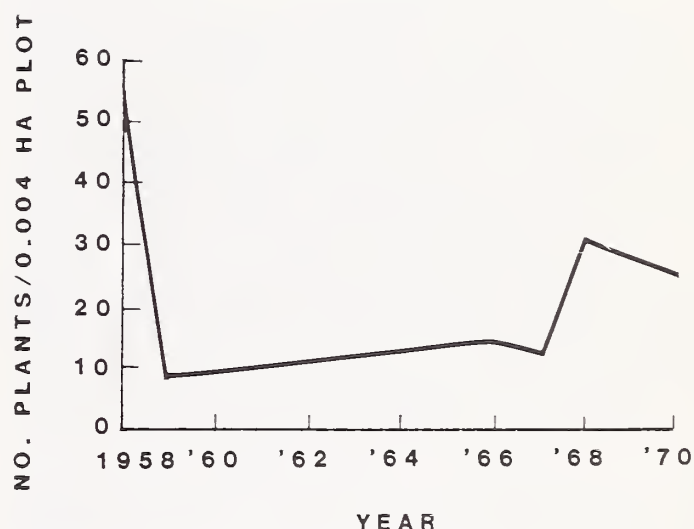


Figure 18.—Density of big sagebrush over a 10-year period following spraying in 1958.

In 1959, Cook and others (1965) treated 240 acres (97 ha) of big rabbitbrush on abandoned dry farmland. The initial treatment of 2,4-D Esteron 76E (50 percent isopropyl and 50 percent butylester) was applied at a rate of 3 lb/acre (3.4 kg/ha) in three replications. Portions of each plot were subsequently retreated in 1960, which gave five different treatments, including the unsprayed control. At the time of treatment, 70 percent of the rabbitbrush plants at Benmore were 7 to 8 years old, and the remainder were generally less than 5 years.

The rate of kill varied with the treatment and by date and year of application. For the initial treatment of 3 lb/acre (3.4 kg/ha), researchers found nearly an 80 percent reduction in foliage. This resulted in 56 percent greater mortality and a 48 percent greater reduction in foliage compared to unsprayed plots. The second application the following year increased the mortality by only an additional 18 percent.

There did not appear to be any appreciable differences in kill rates between application dates June 1 and June 15. However, the results changed from year to year. During 1960 and 1962 no significant differences were noted in mortality rates between the two application dates, but in 1961 the early date was more effective. Researchers could not provide an explanation for these differences.

The rate of application, however, resulted in significant differences in rabbitbrush mortality. In tests using 3- and 4-lb/acre (3.4- and 4.5-kg/ha) rates, over 80 percent of the rabbitbrush was killed and total foliage was reduced by 96 percent. The 2-lb/acre (2.2-kg/ha) rate killed 68 percent of the plants but immediately reduced foliage by 90 percent. Additional applications in 1961 revealed no significant increase in mortality rates.

Researchers monitored the treated areas for 3 years after the last application. The plants that were completely defoliated in the initial treatments were still dead, but those that suffered between 50 and 95 percent defoliation showed evidence of resprouting. Plants with 35 to 50 percent defoliation showed only superficial effects 3 years later. Thus, rabbitbrush can recover from almost total defoliation quite readily.

Because soil moisture is such an important component in successfully treating sagebrush with 2,4-D, researchers examined this variable at Benmore with respect to rabbitbrush. The best kills of rubber rabbitbrush were obtained on the June 1, 1962, application when soil moisture was 13.48 percent at the 1-ft (0.3-m) level and 13.86 percent at the 2-ft (0.6-m) level. The best kill for a mid-June date occurred when soil moisture in the upper 1 foot of ground was 10.24 percent but more than 13 percent at the 2-foot level. At these times, about 80 percent of the rabbitbrush plants were killed. In 1961, when soil moisture was only 11 percent at the two levels, the kill of big rabbitbrush was only 65 percent in early June and less than 50 percent in mid-June. Hence, to be successful, 2,4-D should be applied when soil moisture is above 13 percent in early June, particularly at the 2-ft (0.6-m) level. This area of soil may be most critical because of the taproot configuration of rabbitbrush roots.

Researchers also found that atmospheric temperatures were never critical for the successful application of herbicides on rabbitbrush at Benmore. Generally, the higher the temperature, the better the rate of kill. Overall, if daytime temperatures reached 70° F (21° C), and nighttime remained around 40° F (4.5° C), then soil moisture was the more limiting factor influencing the success of herbicide application (Bonham 1964).

These researchers concluded that a 3-lb/acre (3.4-kg/ha) rate application rate of 2,4-D is high enough in most cases to obtain satisfactory rates of kill for rabbitbrush if soil and weather conditions are favorable. Moreover, when rabbitbrush was controlled, grass yields increased an average of 336 lb/acre (376 kg/ha) two seasons after the herbicide treatments.

A study in the mid-1960's by Cook (1966b) examined the effects of different herbicides on sagebrush and rabbitbrush in Rush Valley. Because both species occur

together in mixed stands, this study sought to determine which herbicide would efficiently kill both in one application.

Picloram (Tordon 22-K), an herbicide that was relatively new at the time, was used on both species. Esters of 2,4-D and 2,4,5-T (Kuron and Esteron 76-E) were also applied during the first week of June 1963. In 1964 and 1965 various mixtures of these three herbicides were applied on mixed stands, plus Tordon 101 (a mixture of 22-K and 2,4-D).

Results of this study have improved our knowledge about the relative effectiveness of herbicides for controlling brush. Esteron and Kuron gave excellent kills of sagebrush but were rather ineffective on rabbitbrush. Tordon 22-K and 101 did well on rabbitbrush but poorly on big sagebrush. The best kills on all locations were obtained with mixtures of Tordon 22-K, Esteron, and Kuron.

Biological Methods

In addition to mechanical and chemical methods of controlling brushy or woody species, studies at Benmore have investigated biological agents of brush control. A review of the subject was made by Frischknecht (1978a). Use of biological agents is a little known field, but one which demands more study.

Mechanical and chemical methods of control generally destroy the photosynthetic processes of plants and dissipate their chemical energy into the atmosphere. On the other hand, biological methods have the advantage of making this plant energy available to animals for conversion into protein that possibly can be used by people. Another important consideration is the role biological agents play in the range ecosystem. While much blame is placed on domestic livestock for causing deteriorated ranges, other biological factors also may be important. Three biological agents of brush control are livestock, insects, and, indirectly, nematodes. (Small mammals are discussed in the next section.)

Livestock as a biological control.—Frischknecht and Harris (1973) found that sheep are effective control agents on sagebrush ranges and reduce the need for costly chemical or mechanical treatments if grazing begins before sagebrush becomes too dense. As described earlier, when brush density was at or below 1.5 plants per 100 ft² (9.3 m²), sheep exerted real controls on growth (fig. 19). In fact, this appears to be the only feasible density where sheep can act as a biological control. But even then, total plant numbers changed little during fall sheep grazing, although a few small plants were eliminated. The effect of sheep grazing was to decrease shrub size and production of seed. Moreover, these researchers found that once sheep grazing was discontinued after 6 years of treatment, sagebrush increased dramatically in both number and size of plants. And the greatest increases were in those plots where sheep grazing had reduced plant size most. Thus, sheep should be used every few years to effectively control sagebrush growth.

Kilpatrick (1965) found that a supplement of 4 ounces (0.1125 kg) protein per day encouraged sheep to use a greater percentage of sagebrush in their diets. Further,



Figure 19.—In area to right of the fence, sheep grazing in late fall greatly reduced the size of sagebrush and rabbitbrush. The area was also grazed by cattle in early spring. Area to left of fence was grazed only in early spring by cattle. Sagebrush density is higher than average in this area as a whole.

sheep can be herded closer together to induce heavier use of browse, and held on sagebrush ranges longer without harm to the vitality of the animals. Sheep owners confirm these findings.

Under the conditions at Benmore, cattle offered no hope of controlling brush species on seeded ranges—except indirectly by deferring spring grazing to let grass become more vigorous (Frischknecht and Harris 1973). Cattle ate only a few flower stalks in the fall—hardly sufficient for effective control. This was true even at the highest stocking densities. In other studies where cattle have been observed eating some sagebrush, it was either (1) because the cattle were overly concentrated and other forage was totally lacking, or (2) a more palatable variety of sagebrush was present than the type at Benmore.

Frischknecht (1978a) reported that defoliation of sagebrush is possible by animals or people brushing against the plant when leaves are frozen and brittle. This researcher selected 12 pairs of plants; one plant of each pair was defoliated by knocking the leaves off in January when the above environmental conditions existed. By early May, the leaf volume of these treated plants was found to constitute only about 5 percent of the untreated counterparts. But by the end of July, most of the defoliated plants had regrown nearly 50 percent of the leaf volume of untreated plants. There were fewer flower stalks produced on the defoliated plants, and 6 of the 12 treated plants produced no flower stalks whatsoever the year following treatment. Therefore, defoliating sagebrush plants by this method is inadequate for effective sagebrush control.

Insects as biological agents.—One population whose importance on the rangelands has not been sufficiently recognized is insects. This group is important because of its vast numbers, rapid dispersal, and rapacious appetites that should be expressed in AUM's. While

some insects (predators) are beneficial to range management because they eat less desirable insects, others damage plants by killing localized cells or destroying seeds and fruit.

Some range managers advocate using insects as biological control agents on undesirable plant species, particularly sagebrush. What is needed is a species of insect that will infest such undesirable plants but not harm species that produce valuable forage for domestic and wild herbivores. For example, the sagebrush defoliator moth (*Aroga websteri*) infests sagebrush. Silken tunnels with fecal pellets woven into them harbor the larvae, which generally defoliate the apical sprouts. In 1962, this moth destroyed up to 15,000 acres (6 070 ha) of sagebrush in Oregon. Another 12 million acres (4,856,400 ha) of ranges were infested to some degree in 1963. Outbreaks of defoliator moths seemed to occur when predator insects failed to control high population buildups. Yet, means of controlling such outbreaks are not known (Frischknecht 1978a).

Another insect known to kill sagebrush is the leaf beetle (*Trirhabda pilosa*) observed in British Columbia in 1954 and 1955. A close relative (*Trirhabda attenuata*) killed over 2,000 acres (809 ha) of sagebrush near Thermopolis, Wyo. For some reason, though, these species do not affect sagebrush plants near anthills.

Thrips are insects that obtain food by sucking out the contents of plant cells, destroying their photosynthetic capabilities. By 1949, scientists had identified 47 species of thrips in Utah, and most were found in sagebrush-grass ranges. Hence, thrips deserve closer attention to help determine their role in the range ecosystem.

Tingey and others (1972) studied thrips and their effects on four plant species at Benmore: sagebrush, rabbitbrush, antelope bitterbrush, and crested wheatgrass. These researchers hoped to discover whether this variety of insect could be useful to resource management goals.

Collections of 20 species of thrips were made during the summers of 1966 and 1967 on a variety of sites at Benmore. Only eight species were found in any significant numbers. Nine species were found only on one plant type, while only one species of thrips occurred on all four plant types. Crested wheatgrass had the most diverse collection of thrips, and antelope bitterbrush the least.

One species (*Anaphothrip zae*) was the most abundant in July and was one of the 12 varieties found on crested wheatgrass. This species generally inhabits grass and sod, and can cause considerable damage to grains and grasses when it occurs in high densities. During this study, however, their numbers were small and thus their damage potential was thought to be limited.

A second species of thrips (*Aptinothrips rufus*) was also collected frequently from crested wheatgrass plants. This species also prefers wheatgrass species in Europe. Although populations could rise high enough to cause considerable damage to plants, they were not found sufficient at Benmore to cause concern.

A third thrips (*Frankliniella occidentalis*) was collected frequently on rabbitbrush in July. It is known to cause considerable damage through feeding on plants

and at times may transmit plant viruses. This variety of thrips reportedly (Ferguson 1963) infests bitterbrush and could negatively affect this valuable deer forage as well as the less desirable rabbitbrush.

Other insect studies.—In addition to thrips, other insects were collected from the four plant species mentioned earlier in a cooperative study between the Intermountain Forest and Range Experiment Station and Brigham Young University. Researchers note the kinds of damage inflicted on plants, but in many cases the extent or quantity of damage was not easily accessible (Jorgensen and Tingey, unpublished report).

In certain locations, spittlebugs were numerous on both big sagebrush and rubber rabbitbrush. Of the two main subspecies of rabbitbrush, the bright green variety was the preferred host over the white-stemmed subspecies. Spittlebugs by themselves seem to have little overall effect on plant vigor, but the quantity of dying and necrotic tissue left after feeding was impressive. The spittle appeared to have a digestive effect on the stem and leaf epidermis, resulting in a noticeably light brown to tan discoloration where insects had fed.

Larvae of the defoliator moth were usually found in most sagebrush stands, although not in sufficient numbers to produce significant damage in the Benmore area during the period of this study. However, sagebrush has been killed during periods of severe outbreaks of this insect in the Benmore area and in northwest Utah.

Jorgensen and Tingey (unpublished report) found many species of aphids on big sagebrush, but the extent of damage to the plant was again difficult to assess. Other insects found on sagebrush include various weevils, lepidopterous insects, and various gall insects. Interestingly, Frischknecht and Baker (1972) reported that a preponderance of the big sagebrush plants killed by meadow voles were those that also showed insect damage in the form of galls.

Cicada nymphs were often abundant on the roots of rabbitbrush. Their presence and relative abundance can usually be determined in midsummer by examining the soil around the bases of individual plants for emergence holes. Cast skins, which usually occur on the lower branches of shrubs adjacent to the emergence holes, can also be used as an index of relative abundance.

Apparently several generations were represented in various sizes of nymphs. Nymphs were usually found from 12 to 36 inches (30.5 to 91.4 cm) below the surface where they live in tunnels that are exposed to a root. Most nymphs were found in the lateral root system rather than on the tap root. Although most infested plants appeared unharmed by their presence, in times of water shortage plant production may be limited by their presence. Adult females often cause considerable damage by ovipositing eggs just under the cambium in the terminal stems, but this type of damage was not observed on rabbitbrush during this study. The fact that nymphs were found underneath these plants would suggest that they originated from eggs deposited in the stems, and upon hatching dropped to the ground and burrowed into the soil.

Both sagebrush and rabbitbrush are particularly susceptible to gall insects. At least three types of galls

were found in the Benmore area. Little is known about the effects of galls on plants. Research shows that they are malformations of the host plants caused by insects that lay their eggs in the plant tissues, which then swell when the eggs start to hatch. Galls appear to be host-specific and differ widely. A study in Utah by McArthur and others (1979) showed that "cotton" galls were most frequently found on specific subspecies of rubber rabbitbrush, notably threadleaf and green rubber rabbitbrush, whereas "callus" galls were found almost exclusively on white rubber rabbitbrush. A type of gall called "mace" was found on all three of the above subspecies of rabbitbrush, but it was the only type of gall found on mountain rubber rabbitbrush.

Jorgensen and Tingey (unpublished report) found that rabbitbrush harbors several species of lepidopterous defoliators. One forms a tunnel by cementing three to six leaves together, and then feeds within the enclosed area. The others generally feed within a protective silk case. No species appears to cause substantial damage. Also, a small chrysomelid beetle causes noticeable damage on rabbitbrush in local areas. These insects feed upon the leaves as adults and in many cases destroy the epidermal tissue.

In the Benmore area, most rabbitbrush plants showed some borer activity, generally in the gnarled portion near the base of the plant. Many old galleries and some new galleries with early instar larvae were found, but few adults or pupae. Most of those collected were weevils, although other families were occasionally observed.

Knowlton (1966) reported that larvae of a weevil killed more than 15 acres (6.1 ha) of rubber rabbitbrush in southcentral Utah. Plant crowns and roots were riddled with tunnels. Mold often followed the insect injury into the below-ground galleries. Smaller tunnels were present in some aboveground stems. Larvae, pupae, and adult weevils were present during late August 1960. Insect numbers were even higher in similar root tunnels of apparently healthy rabbitbrush located around the edges of the dead and dying areas. Dead, moldy adult weevils were fairly common in drying rabbitbrush tunnels and not common in healthy looking plants. Similar damage to rabbitbrush has been noted in other areas.

When the insect study was conducted at Benmore, the blackgrass bug was not found. However, in other parts of the State it had caused heavy damage to crested wheatgrass and other introduced grasses as well as to the native Great Basin wildrye. Researchers have found that grass monocultures are more susceptible to damage by blackgrass bugs than where shrubs such as sagebrush and rabbitbrush occur.

Nematodes.—A cooperative study between the Intermountain Forest and Range Experiment Station and the University of Utah was conducted to determine the effects of plant parasitic nematodes on crested wheatgrass (Havertz 1957). This study was conducted both in the field at Benmore and in the University of Utah greenhouse.

The greenhouse experiments were divided into two parts: (1) 20 clay pots were filled with soil from Benmore—10 of the pots contained nematode-infested soil

and 10 contained soil that had been fumigated with ethylene dibromide; (2) 24 clay pots were filled with soil from Benmore—12 contained nematode-infested soil and 12 contained soil that had been sterilized with steam. In each case, crested wheatgrass seeds were planted in the pots. Subsequently, 467 crested wheatgrass seedlings grown in the greenhouse were processed to compare their growth in treated and untreated pots.

The following conclusions were drawn from the greenhouse study:

1. Crested wheatgrass plants grown in soil that had been fumigated with ethylene dibromide had an average of 26 percent longer top growth than those grown in nematode-infested soil.

2. Crested wheatgrass grown in soil that had been autoclaved had 24 percent more top foliage and 55 percent more root growth than plants grown in nematode-infested soil.

3. Every soil sample obtained from Benmore contained several species of nematodes; among them plant parasitic species (*Tylenchorynchus dubius* and *Tylenchus davainii*).

4. The root tissues of crested wheatgrass were inhabited by many nematodes of a species (*Nothotylenchus acris*) considered endoparasitic by Havertz.

The study at Benmore was conducted in two experimental plots. A plowed and harrowed plot in each of two pastures measured 66 by 66 ft (20.1 by 20.1 m) in dimension. These large plots were divided into quarters; opposite quarters were fumigated with ethylene dibromide, and the other two quarters were left untreated. The plowed areas in both pastures were then seeded with crested wheatgrass. In one pasture, crested wheatgrass grown in soil fumigated with ethylene dibromide produced an average of 16 percent heavier growth than that grown in nematode-infested soil. However, in the other pasture, crested wheatgrass grown in soil similarly fumigated produced generally less growth than the plants grown in nematode-infested soil. This anomaly was attributed to the high moisture content of the soil, which prevented proper aeration after fumigation; the seedlings displayed evidence of phytotoxicity.

This study, both in the greenhouse and in the field, led to the conclusion that plant parasitic nematodes may contribute to the decline of crested wheatgrass yields in the Benmore area. More field experimentation, however, should be carried out under more rigidly controlled conditions and for longer periods.

WILDLIFE HABITAT and BRUSH CONTROL

The Benmore Experimental Range was used to examine how small mammals and nongame birds are affected by control of vegetation. This is an area of increasing interest to wildlife managers. Attempts have been made to study occurrence and number of species, and the response of species and populations to range treatments.

Guidelines on Wildlife Habitat

Small mammals and nongame birds at Benmore have been the subjects of studies on their role in range ecosystems. The following guidelines have been gleaned from those studies:

1. Seeding programs increase pocket and harvest mice numbers where subsequent grazing by cattle is light, and increase deer mice populations where use of forage is heavy.

2. The highest incidence of big sagebrush kill by cyclic eruption of vole populations occurs in draws and low places that have a dense cover of grass and snow accumulation.

3. The summed data for small mammals reveal no differences between four plant control treatments 4 years after application.

4. High plant species diversity and good plant cover appear to enhance rodent populations.

5. Removal of trees will favor increases in grassland-savanna species of birds at the expense of woodland species. However, 1 year after tree removal, numbers and biomass of birds increase and then exceed pretreatment levels.

6. Of three methods of sagebrush removal tested, burning appeared to have the greatest impact on bird populations. Spraying, on the other hand, leaves suitable habitat for some species for a number of years. Chaining appeared to have the least detrimental effect on sagebrush-dependent bird species.

7. Range improvements should be conducted either in the early spring or late summer/early fall to minimize deleterious effect on bird habitat. In addition, large blocks of land should not be treated; rather, strips of vegetation should be left to provide cover and food for the resident avian species.

Small Mammals

Some interest has been focused on small mammals and their role in range ecosystems. A study by Black and Frischknecht (1971) at Benmore sought to determine the kinds of small mammals present on the pastures and their role in the range ecosystem. Traps were set at sample sites and yielded 587 rodents over 2 years. Three species comprised over 98 percent of the catch: deer mice (65.5 percent), western harvest mice (19 percent), and Great Basin pocket mice (14.3 percent). Deer mice were most prevalent on the heavily grazed units. On sites that had not been grazed or plowed, deer mice were the most abundant in units of relatively short cover containing only native plants. Harvest mice were more prevalent on the moderately grazed sites, most abundantly in units of tall cover of mixed native and introduced species. Pocket mice were most abundant in nongrazed areas with a mixture of native and seeded grasses and where grass cover was heavier than on any other site.

Studies have shown that some insects increase where grazing is heavy. Because insect larvae is the most important food for deer mice in summer and fall, this may explain why the mice were abundant in heavily grazed areas and areas with the least amount of cover.

Seeds are the most important food in the diet of harvest and pocket mice. Hence the mice are generally found in sites with heavy ground cover. Harvest mice were notably rare in nongrazed native grasses that tended to be shorter than adjacent introduced grass stands.

Black and Frischknecht (1971) suggest that seeding programs increase pocket and harvest mice numbers where subsequent grazing by cattle is light. In contrast, seeding programs increase deer mice populations where use of forage is heavy. There was no correlation evident between the relative abundance of any rodent and species of grass.

Voles kill and damage sagebrush and other shrub species by girdling the stems and branches. In winter 1968, voles killed and damaged big sagebrush over sizable areas of Utah and Nevada. Similar reports came from southern Idaho and Montana. Thus Frischknecht and Baker (1972) conducted a study to assess the possibility of taking advantage of peak vole populations to improve ranges infested with big sagebrush. Eight sampling areas near Benmore were selected to determine the amount of brush killed and the species of vole present. All sample areas were located above 6,500 ft (1 980 m) because little vole damage was noted below this elevation. Average annual precipitation on the study sites ranged between 15 and 20 inches (38 and 51 cm), of which 60 percent fell as snow. Five of the study areas were in drainages where snow lasted all of winter.

The species of vole responsible for girdling was determined by one night's trapping with two snap traps placed on each of 80 plots. During the equivalent of 160 trap nights, 23 long-tailed voles and 20 deer mice were captured. The deer mice were uniformly distributed, but the voles were caught more at the plots in higher elevations. The trappings followed the incidence of heavy brush kill.

The researchers found that some sagebrush stems were girdled to the level of the snow—up to 20 inches (51 cm) in some areas.

Overall 59 percent of the big sagebrush plants on the sample plots were killed completely by voles and 28 percent showed some damage. The highest incidence of kill was observed in draws and low places that had a dense cover of grass and snow accumulation. This finding supports observations by Mueggler (1967), who noted that the greatest sagebrush kill by voles in Montana occurred in protected spots where snow accumulation was continuous. Apparently a good herbaceous cover is conducive to the buildup of high vole numbers because they can form runways through the accumulated litter and thus escape predation. Another important factor appears to be persistent snow cover.

Of real significance in the study by Frischknecht and Baker were two areas left ungrazed by livestock during 1968. On these areas, the voles killed most of the sagebrush the following winter, boosting the yields of the herbaceous species. Some girdling was also observed on rubber rabbitbrush and yellowbrush, the former only in canyon bottoms, the latter everywhere. Up to 50 percent of the rabbitbrush plants were killed completely, and most of those surviving showed some damage.

Few of the yellow brush plants were killed. About one-half showed no damage at all. No damage at all was observed on herbaceous species.

Knowing the requirements for good vole habitat, ungrazed shrub-grassland communities conceivably might have been influenced by voles over the years prior to settlement. Microtine populations are known to be cyclic, but they are difficult to predict. Some researchers observed a 4-year cycle in vole populations. A better understanding of the factor or factors that trigger eruptions in such rodent populations would be highly valuable.

Baker and Frischknecht (1973) focused on the impact of small mammals on renovated rangelands where pinyon and juniper had been removed. Six areas were studied, most near Benmore. Four treatments of pinyon-juniper rangeland were sampled: (1) untreated, old stands with little understory; (2) chained two ways and seeded; (3) chained, windrowed, and seeded; and (4) chained, windrowed, seeded, and burned. The equivalent of 7,350 trap nights produced 1,321 small mammals of 13 species:

Species	Percent of total
Deer mice	83
Great Basin pocket mice	7
Long-tailed voles	2.8
Western harvest mice	2.1
Chisel-toothed kangaroo rats	2.0
Total	96.9

Initially, clearing reduced rodent populations. In the second year after treatment there was a dramatic increase in the catch of deer mice and pocket mice, except on the untreated areas. In the third and fourth years after treatment, the catch dropped to a lower level but remained higher than before treatment. Some preference was indicated in individual years for heavier cover in some, but not all, situations. In the second year, some preference was shown for slash cover, especially windrows. Voles showed a strong preference for heavy cover; thus, piling trees creates vole habitat. The few pocket mice caught showed no differences between treatments.

Apparently, a high degree of edge afforded by the narrow strips of different treatments at Benmore created a generally favorable habitat for small mammals in comparison to other areas where second-year catches were not as large as at Benmore. Four years following treatment, the summed data for small mammals revealed no differences due to treatment. These findings were further substantiated by Baker (unpublished report) in other trapping studies.

A more recent rodent population study reported by Nichols (1972) and Nichols and others (1975) examined sagebrush communities representing three elevational gradients near Benmore: 5,100 ft (1 554 m), 5,700 ft (1 737 m), and 6,500 ft (1 980 m). The three areas were live-trapped simultaneously for six trapping periods. These catches were toe-clipped for identification, and species, sex, age, weight, trapping station, and general condition of the rodent were recorded. At the end of

the six trapping periods, each area was "kill-trapped" for comparison with the previous live-trapping periods.

This study indicated that the lowest elevation areas had a higher population total early in the summer followed by a decline and eventual leveling off in the fall. The intermediate elevation area showed three separate population peaks with the highest peak coming in late summer, around the middle of August. The highest elevation area showed a gradual increase in rodent numbers that also peaked about the middle of August and then declined by early September.

Western harvest mice were found only at the lower elevation sites and Great Basin pocket mice only at the highest elevations. In all three gradients, the most common species were deer mice and the least chipmunks.

This study revealed that the highest area had the most diverse rodent presence and was also the most stable in terms of the annual cycle for rodent populations. Plant species diversity was also the greatest on this site. Whether there is a relationship between the presence of rodents and the presence of sagebrush was not addressed by these researchers. However, high plant species diversity and good plant cover appear to encourage increased rodent populations at the elevations studied.

Nongame Birds

The Benmore Range has been used in recent years to examine the effects on small mammals and nongame birds of manipulating vegetation areas of increasing interest to wildlife managers. Baker (unpublished report) investigated nongame bird responses to pinyon-juniper removal and range seeding. One study area had been treated by chaining and windrowing of trees and seeding forage species—introduced wheatgrasses, alfalfa, and sweetclover.

Baker found that number of individuals, number of species, and biomass of birds declined markedly the first year following tree removal. But the next year, the second growing season for the seeded forage species, numbers and biomass increased dramatically and exceeded the pretreatment level. Species of grassland birds, principally meadowlarks, vesper sparrows, lark sparrows, horned larks, and common ravens, accounted for most of this increase.

Other bird species were negatively affected by tree removal at Benmore. The plain titmouse, usually considered to be an obligate of pygmy conifers, was one of the more common birds before treatment, but disappeared after treatment. Tree removal also decreased the numbers of gray flycatchers observed on the treated area. Other species negatively impacted by removal of the trees were the scrub jay, the chipping sparrow, and the common bushtit.

Finally, Baker noted that a number of bird species exhibited variable responses to tree removal. Brewer's sparrows, for example, declined immediately after treatment but returned to their pretreatment levels in 1 year. Similar responses were noted for housefinches and mountain bluebirds. Grassland birds continued to be important on treated areas for at least 7 years following treatment.

A second study conducted by Castrale (1981) investigated the effects of controlling sagebrush on nongame birds. Three 40-acre (16-ha) study sites were selected near the Benmore area. One site where sagebrush had reinvaded since treatment in 1963 was designated as the control. Of the two sites recently manipulated, one was chained and seeded to grasses and the other was burned after having been previously seeded.

Castrale found that total nongame bird densities and numbers of species were similar on all three sites. However, densities of certain species differed between sites. Brewer's sparrows and sage thrashers, for example, decreased markedly on the treated sites and thus have been termed sagebrush obligates. Castrale found that burning more severely affected their numbers than did chaining. In fact, if the burned site had lacked patches of sagebrush missed by the burn, Brewer's sparrows would probably have been absent entirely as a breeding bird.

For the most part, densities of vesper sparrows and western meadowlarks were not noticeably different between control and burned sites. Vesper sparrows were essentially absent from the chained site, which is difficult to explain. Western meadowlarks, considered to be a true grassland bird species, showed slightly higher densities on treated areas.

The horned lark was the only species to show decidedly higher densities on sites subjected to sagebrush control. Widespread in distribution, horned larks are most common in disturbed grassland habitats, and the treated sites contained more bare ground and less litter cover than did the control. Horned larks selected open areas on all sites and were occasionally seen perching at the edges of sagebrush islands.

Differences in bird populations among sites may also have been due to the effects of sagebrush removal on the food base. Spring and summer food habits range from totally insectivorous for sage thrashers, through highly insectivorous for Brewer's sparrows and western meadowlarks, to predominantly granivorous for vesper sparrows and horned larks. Biomass and composition of insect communities would be affected by changes in the biomass and species composition of plant communities. These changes would alter the availability of preferred and required foods, causing changes in the suitability of sites that may be reflected by differences in bird densities.

These findings from Castrale's study are consistent with bird responses reported for sagebrush control by spraying except that burning caused more immediate and persistent reductions in sagebrush habitat. Effective spraying of shrubs continues to offer cover and suitable nest sites for shrub-dependent birds (such as Brewer's sparrows) for several years after treatment. On the other hand, effective burning consumes whole shrubs, and the effects on bird populations are immediate. Chaining has the least detrimental effect on sagebrush-dependent birds.

Castrale concluded that management objectives for sagebrush bird communities should be to provide sufficient habitat compatible with other uses for maximum diversity and density of birds. To effectively provide

these habitats, Castrale recommended that areas should be chained, burned, or sprayed in strips of 328.1 ft (100 m) wide rather than in large blocks. Untreated strips should be 328.1 to 656.2 ft (100 to 200 m) wide to provide sufficient areas for sage thrasher populations. In addition, sagebrush areas should be treated prior to territory establishment by birds in the early spring or after birds have left the area in late summer or early fall. In all areas, scattered shrubs are desirable because they are frequently used as perches by all bird species.

NOXIOUS WEEDS

A problem with reseeded and overgrazed rangelands in the Great Basin area has been the proliferation of noxious weeds, most of which are introduced and some of which are poisonous. Cheatgrass, halogeton, Russian thistle, claspig pepperweed, and bur buttercup have all become problems. All these species tend to invade disturbed or poor condition areas, and all have become established components of range ecosystems, requiring special management techniques.

Guidelines on Noxious Weeds

Several studies at Benmore on dangerous and non-nutritive weeds have resulted in the following management guidelines:

1. The intensity of grazing strongly affects the rate of invasion of halogeton into stands of crested wheatgrass: the heavier the grazing, the more likely halogeton is to appear.
2. Halogeton begins to decline on pastures where spring grazing is discontinued and switched to summer or fall grazing. At least 2 years of deferment is necessary to decrease frequency.
3. Halogeton occurrence favors disturbed areas; abundance depends on year-to-year precipitation.
4. A number of control methods, including successful reseeding of depleted areas with perennial grasses, will slow the advance of halogeton.
5. The best insurance against invasion by halogeton is a vigorous stand of perennial range plants and variations in grazing.
6. The density of bur buttercup appears to be related to number of species present and frequency of introduced species. It is more abundant in heavily grazed pastures and has a close positive association with other annual weeds.
7. Bur buttercup has no forage value for livestock. While the weed should not be enhanced, total elimination is impractical. Control of bur buttercup by herbicides is possible where valuable perennial species would not also be killed.

Halogeton

Halogeton was first discovered in 1934 near Wells, Nev. Related to Russian thistle, it is an introduced annual from Asia that has spread over vast areas of the salt deserts in the American West. Found in only eight Western States in 1957, halogeton has since spread to 10 more States and continues to advance. So far, control

measures have not been successful. In 1942 near Wells, 100 sheep died after eating halogeton on what was previously good livestock range. Before these deaths, many sheep owners thought halogeton to be a good source of forage. But it contains high levels of oxalic acid, a highly toxic element. As late as 1971 in southwestern Utah, 1,300 head of sheep died in one night from eating halogeton.

Halogeton was first observed on pastures at Benmore in 1952 (Frischknecht 1967, 1968a). By 1957 it had spread to 22 of the 28 100-acre (40.5-ha) pastures. Scientists believed that the seeds of this plant probably entered Rush Valley from the west in the late 1940's, perhaps carried along roadways or stock driveways. First observed on "slick" spots in Benmore's most northern pastures, consideration was initially given to eradicating the plant. However, researchers decided to study halogeton to learn more about its physical and chemical characteristics.

At the time of its original invasion, the grass stands at Benmore were 10 to 14 years old and well established. Researchers plotted the distribution of halogeton each year between 1952 and 1958 during early September when it was most easily recognizable. The soils supporting halogeton and those without were analyzed, precipitation recorded, and photographs taken.

Frischknecht found that intensity of grazing strongly affected the rate of invasion of halogeton into stands of crested wheatgrass—the heavier the grazing, the more likely halogeton was to appear (fig. 20). By 1956, the heavily grazed units had 83 percent of all the halogeton plants, compared to only 15 percent in moderately grazed units, and 2 percent in the lightly grazed pastures. In the latter two cases, halogeton was generally confined to the spots where livestock grazed heavily. In 1961, halogeton began to decline on pastures where spring grazing was discontinued and switched to summer or fall grazing. By 1964, halogeton was found only on units where spring grazing was still continued. Frischknecht found that at least 2 years of deferment from heavy spring grazing were necessary to decrease the frequency of halogeton on seeded rangelands.

Frischknecht concluded that, because the plants moved from north to south at Benmore, the halogeton seeds were probably spread by intermittent winds, animals, and vehicles. He also believed that the spread of halogeton was directly related to topography and soils. Most halogeton plants occurred on ridges that had experienced sheet erosion and loss of topsoil. Soil moisture was also lower on these areas than in surrounding areas. These soils had a higher salt content, which made these areas unfavorable to the growth of perennial grasses but which was especially favored by halogeton. Evidence also suggested that the presence of alkali bees in an area may be an indicator of favorable conditions for halogeton. The same conditions required for bee nesting apply to the establishment of this noxious annual.

Halogeton also appeared to favor disturbed areas where other species offered little competition. Roadsides, rodent workings, gravel pits, borrow pits, airstrips, and areas around stock watering tanks are likely places for halogeton to invade.



(A)



(B)

Figure 20.—(A) *Halogeton* grows profusely on a heavily grazed unit. (B) The weed is confined to heavily grazed spot in lightly grazed range.

The abundance of halogeton was also found to be dependent on year-to-year precipitation. Because halogeton seeds can persist for up to 10 years before germinating, outbreaks can fluctuate with rainfall. At Benmore, the greatest increase occurred after higher than normal July through September precipitation in 1954 followed by above average May to June precipitation in 1955.

Fischknecht (1968a) reported a number of control methods, such as successful reseeding of depleted areas with perennial grasses, will slow its advance. In addition, patches of halogeton can be mowed, bladed, sprayed, or grubbed, but at some expense. Applications of 2,4-D at a rate of 1.25 lb per 5 gallons (0.6 kg/18.9 liters), of water for example, have been effective in killing nearly 100 percent of the existing halogeton in the spring. But the seeds of past years maintain the stand if perennial grasses are not immediately established. Applications of Tuperson (a Dupont product whose common name is Siduron and is urea based) often kill even the halogeton seeds.

Because similar conditions to those at Benmore exist elsewhere, it appears that halogeton has not spread to its full range of adaptability. The best insurance against the invasion of halogeton is a vigorous stand of perennial range plants; variations in grazing, particularly occasional deferment during the growing season, helps keep these stands vigorous.

Bur Buttercup

Bur buttercup, a native plant of southeastern Europe, is a low-growing, highly adaptable winter annual that has spread rapidly since first collected in America in 1932 near Salt Lake City. As with many highly adapted introduced weeds, by the time it was recognized as undesirable it had gained such a foothold as to make total control impractical.

By the mid-1960's, the species appeared to occupy vast areas that once supported cheatgrass; some stockowners indicated they were unable to get stands of common rye started on areas where bur buttercup had invaded. The species also appeared to be well adapted to "alkali" spots that support heavy stands of halogeton in the late summer and fall. Apparently, seeds are dispersed by water, livestock, and other animals as well as by people and vehicles. By 1965 the species was observed in the crested wheatgrass pastures at Benmore. Because of its rapid spread and potential as a weed, a cooperative agreement between the Forest Service and the University of Utah was initiated in 1966 to study its life history, ecology, and distribution.

Buchanan (1969) noted that a scarcity of species, together with a high frequency of introduced species, might identify areas especially prone to invasion by bur buttercup. Density of bur buttercup was highest in the low frequency halogeton communities that also had a high frequency of introduced species. Although greasewood and shadscale communities had relatively high frequencies of introduced species, either the greater number of competing species or some quality of the abiotic environment apparently restricted production of buttercup. While the greasewood and shadscale sites appeared environmentally similar in respect to surface soil characteristics, the buttercup was more prominent under greasewood.

The response of buttercup in crested wheatgrass and western wheatgrass types was quite similar except for production. These two sites also appeared similar as to their relative disturbance.

Bur buttercup was more abundant in the heavily grazed pastures at Benmore. The association of bur buttercup with other species in the grazed pastures indicated a close positive association with the weedy species, halogeton, clasping pepperweed, cheatgrass, and poverty weed. Buttercup is also positively associated with salt-affected halogeton and salt-free sagebrush environments.

Bur buttercup has no forage value for livestock and no evidence suggests that the plant should be enhanced. On the other hand, total elimination is impractical. Local control is possible on cultivated lands simply by cultivation in early spring before seeds have formed.

On rangelands, control by herbicides is possible where valuable perennial species would not be killed by the treatment. Frischknecht has observed that burning after plants have dried will kill the seeds if done before disturbance causes burs to disintegrate.

Competitive and allelopathic effects of bur buttercup on range grasses and wheat were reported by Buchanan and others (1978). Germination studies using both glass and soil systems were used so that results might be extrapolated to field conditions. Three studies were carried out:

An in vitro study in petri dishes was designed to test the effects of leachate from bur buttercup tissue on germination and root growth of grasses. The leachate having an osmotic concentration of 1.8 atmospheres and a pH of 5.5, reduced germination and root growth of crested wheatgrass, tall wheatgrass, winter rye, Gaines fall wheat, and Delmar fall wheat.

The second study involved testing effects of two concentrations of bur buttercup leachate on seven grasses and three forbs in potted silty clay soil from Benmore, plus testing two of the seven grasses in sand. In the silty clay soil, bur buttercup tissue reduced germination of only one species, crested wheatgrass, and only for the heavier concentration of bur buttercup tissue. However, in sand the germination of both species tested (crested wheatgrass and Gaines wheat) was significantly reduced by both concentrations of bur buttercup tissue. The average weight of surviving plants of crested wheatgrass was also reduced by the heavier concentration of buttercup tissue.

The third study involved planting seeds of bur buttercup in the same rows with nine grasses in a cold frame at Benmore. Here bur buttercup significantly reduced growth of fairway and western wheatgrasses. Whether this was due to allelochemic effects or simple competition is unknown. Winter rye and both Gaines and Delmar wheat were far more effective in suppressing growth of bur buttercup than were three of the perennial grass species because they germinated and grew more rapidly than the perennials in the cold frame.

RANGE FERTILIZATION

While many methods have been used to maintain the vigor and density of seeded rangelands, few operators have used fertilizers to improve their lands. A major reason for this is expense. Nevertheless, several studies at Benmore examined the feasibility of applying commercial fertilizers, observed the effects of fertilization, and determined the appropriate application rates.

Guidelines on Fertilization

The fertilization studies have resulted in the following guidelines:

1. Only nitrogen and phosphorus are useful on native perennial rangelands, but because of expense, their use is prohibitive.

2. Carryover from year to year increases with increased rate of nitrogen application. To maintain yields, fertilizers need to be applied almost annually, or at least every 2 years.

3. Nitrogen alone increases forage yields of grasses. Lighter applications of nitrogen yield the same or even more forage than heavier applications.

4. Phosphorus alone seems to produce no significant results on grass except at the higher application rates. Phosphorus also does not significantly improve response due to nitrogen when applied together.

5. Phosphorus does not appear to increase nutritive quality of forage. But nitrogen increases protein, available carbohydrates, and total energy as application rates increase.

6. Fertilization apparently increases production of forage and its use by livestock.

7. Without sufficient rainfall, use of fertilizers may be futile and wasteful.

Levels of Fertilization

Previous fertilization studies show that only nitrogen and phosphorus have any promise on native perennial ranges. Thus, Cook (1965) designed several studies to examine the effects of different rates of nitrogen and phosphorus applications. The nitrogen fertilizer consisted of 33.5 percent ammonium nitrate, and the phosphorus fertilizer was 45 percent treble superphosphate. Cook's studies examined the comparative effects of light and heavy applications of nitrogen and phosphorus at four levels: 20 and 40 lb/acre (22.4 and 44.8 kg/ha); 30 and 60 lb/acre (33.6 and 67.2 kg/ha); 40 and 80 lb/acre (44.8 and 89.7 kg/ha); and 90 lb/acre (100.9 kg/ha). On sample plots, nitrogen and phosphorus were applied separately and in all combinations on seeded areas at these rates. The results are revealing.

Yields.—Cook noted that even small amounts of nitrogen alone (20 lb/acre) increased yields the first season after treatment compared to untreated plots. However, phosphorus applications seemed to produce no significant results except at the higher application rates. For example, when 20 lb of nitrogen and 20 lb of phosphate were applied together, slightly less forage was produced than when 20 lb of nitrogen was applied alone. But 40 lb of nitrogen with 40 lb of the phosphate produced more forage than either 20 or 40 lb of nitrogen by itself.

In general, Cook found that in each case the lighter application rate of nitrogen yielded the same or even more forage than the heavier rate. For instance, the 30-lb-per-acre (33.6-kg/ha) rate yielded an increase of 885 lb/acre (992 kg/ha) of forage over unfertilized plots, whereas the 60-lb rate resulted in a 805-lb/acre (902-kg/ha) forage increase. The same results were noted for the 40/80 application rates. When 90 lb/acre (100.9 kg/ha) of nitrogen was applied, plants experienced early wilting and turned brown 2 weeks earlier than untreated plots.

Carryover.—When nitrogen was applied at the lightest application, Cook found no significant carryover beyond the first year. However, carryover became more marked as nitrogen application rates increased. At the 30/60 rates, carryover responses were noted for the next 2 years when treated plots were compared to the untreated plots. Moreover, the most dramatic carryover was found on a deteriorated wheatgrass pasture that,

by the fourth year after fertilization, was still producing 196 lb more forage per acre (219.7 kg/ha) than the untreated plot. Thus, it appears that fertilization can be used to good effect to bring back the vigor on deteriorated grass pastures.

Seedling response.—Neither nitrogen nor phosphorus had any beneficial effect upon seedling emergence, plant survival, or subsequent production when applied at the time of seeding.

Plant growth.—No significant differences were found in leaf length or plant height between fertilized and unfertilized plots. However, the higher rates of nitrogen application increased both crown diameter and number of seed heads per plant. Radial spread of roots was not increased by the increased application of nitrogen. In fact, lateral root development was actually greater for untreated wheatgrass plants. Thus, higher rates of nitrogen application may impede root vigor.

Chemical content of forage.—Phosphate at any rate of application did not appear to affect the nutritive quality or protein content in any way. However, nitrogen applications increased total protein, available carbohydrates, and total energy as application rates increased. For instance, 40 lb (44.8 kg) of nitrogen produced 65 percent more total protein per acre and about 35 percent more total digestible nutrients when compared to unfertilized plots. Ash and cellulose were higher in plants on unfertilized plots.

Recovery efficiency (percent nitrogen).—Most of the recovery of applied nitrogen occurred the first year of application. At the 20/40 level, 80 percent of the nitrogen was recovered the first year. At the 30/60 level, 70 percent was recovered the first year. The remainder in both cases was recovered over the next 2 years. Cook noted that recovery efficiency decreased as application rates increased.

Utilization.—The application of phosphorus, either at the light or heavy rates, did not increase utilization of either crested or pubescent wheatgrass. However, use was affected by differing rates of nitrogen applications. In all cases, palatability increased with the increased application of nitrogen. As a result, use by cattle increased correspondingly, but the differences practically disappeared by the end of the second growing season after application. Higher applications of nitrogen also appeared to promote more uniform grazing and thus reduced the number of wolf plants in treated pastures.

Soil conditions.—Fertilized plots had less soil moisture during the early summer than did unfertilized plots. Moreover, soil moisture decreased much more rapidly on fertilized plots during the spring and early summer, in large part because there was simply a greater amount of forage growing at a faster rate on the more heavily fertilized plots.

Applications of nitrogen increased the efficiency of soil moisture use compared to untreated plots. Plants on fertilized plots removed 12.37 percent of the moisture and produced 282.3 lb of forage per acre (316.4 kg/ha) for each 1 inch (2.5 cm) of water removed. By contrast, plants on unfertilized plots removed 12 percent of the soil moisture (nearly the same) but produced only 181.1 lb

of forage per acre (203 kg/ha) for each inch of water removed—36 percent less forage per inch of water used.

Feasibility of Fertilization

Between 1971 and 1974, Roberts (1977) conducted a study on the economic feasibility of fertilizing rangelands. He hoped to determine (1) the optimum fertilizer reapplication frequency; (2) the most profitable season of application; (3) the most profitable rate of application, including carryover response; (4) livestock responses to fertilization; and (5) costs and returns to ranching operations of range fertilization.

Two pastures at Benmore were fertilized at rates of 0, 25, 50, and 100 lb/acre (0, 28, 56, and 112 kg/ha) and at different seasons of the year. Roberts reported a number of interesting findings.

Forage response.—More than 10 inches (25.4 cm) of annual precipitation is necessary to result in any significant forage response. While levels at Benmore are generally greater than this, operators should be aware that without sufficient rainfall, application of fertilizers may be futile and wasteful. However, Roberts did report that higher rates of fertilization produced plants with wider leaf blades and a darker green color than plants on control sites. Moreover, nitrogen fertilization stimulated early growth in crested wheatgrass. Thus, range readiness of this plant was advanced through fertilization, but strength of response is influenced by levels of precipitation.

Carryover response.—None of the plots studied showed any significant carryover response to fertilization from one season to the next. Thus, to maintain production yields, Roberts concluded that fertilizers would need to be reapplied almost annually or at least every 2 years.

Season of application.—This study was unable to conclusively determine the optimum season of application. Some plots did not respond favorably to initial applications of fertilizers because of inadequate precipitation, and there were no significant carryover effects.

Livestock response.—Fertilization produced an increased carrying capacity on the study sites. The animal unit day (AUD) of grazing changed from 837.76 on unfertilized plots to an average of 1,444.35 on plots fertilized at a rate of 100 lb/acre (112 kg/ha) of nitrogen—an increase of 72 percent. This increased capacity was not too different from plots fertilized at a rate of 50 lb/acre (56 kg/ha), which still resulted in a 60 percent increase of AUD's over unfertilized plots.

This increased amount of grazing led to an increased weight gain for livestock per acre of forage grazed. Calves made the greatest gains while the differences in gains in cows between the different rates of application were not significant.

Roberts concluded that using livestock to harvest fertilized forage on rangelands is economically impractical. Costs of nitrogen fertilizer place it outside economic use by resource managers. In addition, low beef prices also make the use of fertilizers prohibitive. Finally, while the forage may benefit, the effects are temporary and are largely lost after one season.

Other Studies

Frisehknecht (1968b) studied effects of commercial fertilizers on plots inside and outside permanent exclosures at Benmore. Nitrogen in the form of ammonium nitrate was applied at the rate of 100 lb/acre (112 kg/ha), phosphate in the form of treble superphosphate at 300 lb/acre (336 kg/ha), and a combined NPK fertilizer in the ratio 6-10-4 to give 100 lb of nitrogen per acre. Applications were made on separate plots in December 1967, January 1968, and March 1968.

The addition of nitrogen produced herbage yields about three times that of untreated plots both inside and outside the exclosures (fig. 21). Phosphorus alone increased herbage yields only about 15 percent. There were no consistent differences in herbage yields between nitrogen alone and the NPK treatment, showing that phosphorus and potassium had little or no effect. Nitrogen increased the number of flower stalks between 5 and 10 times those for untreated plots. Again there were no differences between the nitrogen only and the NPK treatment.

Date of application had little or no effect on herbage yields or numbers of flower stalks, probably because of above average spring precipitation in 1968. A total of 8.38 inches (21.3 cm) precipitation fell between December 13, the first date of nitrogen application, and June 8 when most flower stalks had appeared. Precipitation of 5.68 inches (14.43 cm) fell between March 1 and June 8, which is about 150 percent of the long-term average for this period. There was no appreciable carryover of nitrogen the following year from these applications.

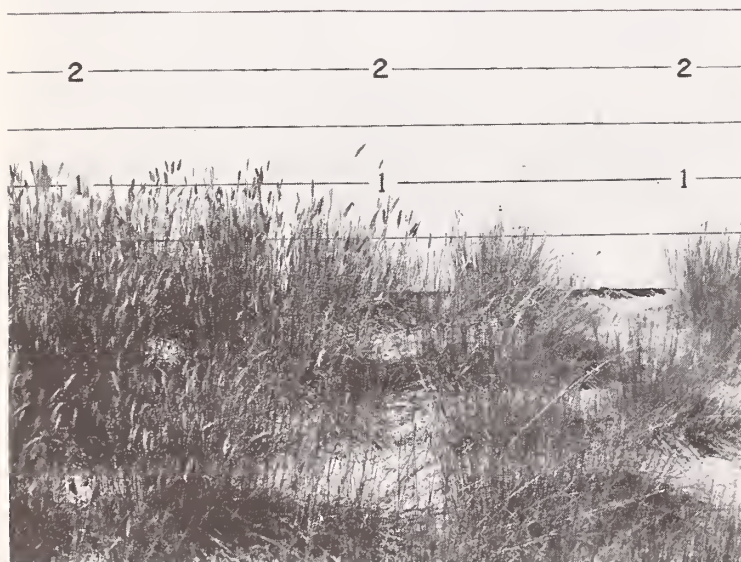


Figure 21.—Fertilized grass (left) shows increased forage and seed stalk production over nonfertilized area (right).

CURRENT RESEARCH AT BENMORE

Although the level of research has tapered off significantly at the Benmore Experimental Range during recent years, the Utah Agricultural Experiment Station continues to use its facilities to conduct a breeding study of interest to range managers and livestock producers.

The Hereford has been the standard beef animal used by livestock operators throughout much of the West. But the livestock production situation has changed dramatically in recent years. Capital and operational costs per cow have increased markedly. Hence, operators are looking for greater returns on their investments. Because the possibility of expanding one's herd size is limited, the alternative has been to improve production per cow by optimizing breeding rates and producing larger calves.

The high production of nutrients of crested wheatgrass during the critical early spring period offers opportunity for using cows of higher milking ability without suffering a penalty of delayed rebreeding. The challenge facing the range cow-calf owner is to balance genetic abilities of cows and calves to the feed production ability of the range.

For these reasons, the Utah Experiment Station is conducting a long-term study to investigate alternatives to straight Hereford breeds. For 3 years (1977 through 1979) Hereford bulls were bred with three selected genotypes of cows: Hereford, Simmental, and Angus. At the conclusion of this first phase, researchers reported that the Hereford-Simmental breed produced a larger calf after 205 days (Stenquist and Bennett 1981). This advantage in weight held true in each of the 3 years, averaging a full 75 lb (34 kg) heavier than the straight Hereford breed and 40 lb (18.1 kg) heavier than the Hereford-Angus combination. Moreover, while the Hereford-Angus combination exhibited the shortest calving interval (357 days), the Hereford-Simmental combination was a close second (359 days). The straight Hereford breed had a calving interval of 367 days. All three groups were satisfactory in this.

This study found that all calves, regardless of breed, sold at equally high prices, and that the Hereford-Simmental cross had slightly higher daily gains in the feedlot. Carcass quality was also equivalent to other breeds. However, the Hereford-Angus cross had some advantages over the other two crosses; it has not shown any cancer eye nor sun-scald—two problems with the straight Hereford and Hereford-Simmental cross.

In the second phase of this study, cows were bred with Charolais and Limousin bulls to produce calves of greater growth potential. Both of these breeds are recognized for their high growth weights. Charolais and Limousin-sired calves had heavier birth weights than the Hereford-sired calves (table 2), but calving difficulty was not high in this study. There was no difference in weaning weight of calves sired by bulls of these two breeds, but their calves were 30, 13, and 31 lb heavier than Hereford-sired calves from Hereford, Angus-Hereford, and Simmental-Hereford cows, respectively (table 3).

In the third phase of this study (Bennett 1984), new genetic material is being added in an attempt to eliminate the cancer eye and sun scald problem while still retaining the high reproductive and high weaning weights as shown by the Hereford-Simmental cross cows. Sires of the Tarentaise breed, a solid red breed with heavy pigmentation around the eyes and on the udder and with good milk production, have been crossed on the cows. Yearlings and calves of the cross show great promise at this stage. These Tarentaise crosses, as cows, will be compared to Angus-Hereford and Hereford-Simmental cows to determine their relative ability as mother cows for this range situation.

Table 2.—Birth weights of crossbred calves (Hereford x Hereford, Simmental x Hereford, Angus x Hereford) in 1980

Sire	Dam			Average
	H x H	S x H	A x H	
	-----Pounds (kg) -----			
Charolais	85.7 (38.9)	103.2 (46.9)	88.7 (40.2)	92.5 (42.0)
Limousin	81.8 (37.1)	98.5 (44.7)	79.4 (36.0)	86.6 (39.2)
Average	83.8 (38.0)	100.8 (45.7)	84.0 (38.1)	89.6 (40.6)Q

Table 3.—Comparative 205-day weaning weights for Hereford and crossbred dams and Hereford and "exotic" sires

Cow breed	Sire breed	
	Hereford	Charolais and Limousin
	-----Pounds -----	
Hereford	430	460
Angus x Hereford	462	475
Simmental x Hereford	505	536

REFERENCES

- Anonymous. WPA history of grazing. Works Progress Administration Writers' Project. MS 8. Logan, UT: Utah State University Archives and Special Collections; n.d.
- Baker, Maurice F.; Frischknecht, Neil C. Small mammals increase on recently cleared and seeded juniper rangeland. *Journal of Range Management*. 26: 101-103; 1973.
- Barney, Milo A.; Frischknecht, Neil C. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. *Journal of Range Management*. 27: 91-96; 1974.
- Bennett, James A. Benmore field day report. Logan, UT: Utah Agricultural Experiment Station; 1984. 5 p. Unpublished report.
- Bennion, Glynn. Re-grassing the range. *National Wool Grower*. 14: 19-21; 1924.
- Bennion, Harden. The Bennion family of Utah. Vol. 1. Salt Lake City, UT: Bennion Family Association; 1931.
- Black, Hal L.; Frischknecht, Neil C. Relative abundance of mice on seeded sagebrush-grass range in relation to grazing. Research Note INT-147. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 8 p.
- Blaisdell, J. P. Competition between sagebrush seedlings and reseeded grasses. *Ecology*. 30: 512-519; 1949.
- Bonham, Charles D. The effect of date and rate of application of 2,4-D on control of big and little rabbitbrush. Logan, UT: Utah State University; 1964. 29 p. M.S. thesis.
- Buchanan, Bruce A. The life history and ecology of bur buttercup (*Ranunculus esiculatus*). Salt Lake City, UT: University of Utah; 102 p. 1969. M.S. thesis.
- Buchanan, Bruce A.; Harper, Kim T.; Frischknecht, Neil C. Allelopathic effects of bur buttercup tissue on germination and growth of various grasses and forbs in vitro and in soil. *Great Basin Naturalist*. 38: 30-96; 1978.
- Castrale, John S. Use of managed sagebrush grasslands by bird populations. Provo, UT: Brigham Young University; 1981. 61 p. Ph.D. dissertation.
- Cook, C. Wayne. Crops for diverted dryland wheat acres. Extension Circular 251. Logan, UT: Utah State University Agricultural Experiment Station; 1956. 12 p.
- Cook, C. Wayne. Sagebrush eradication and broadcast seeding. Bulletin 404. Logan, UT: Utah State University Agricultural Experiment Station; 1958. 23 p.
- Cook, C. Wayne. Plant and livestock responses to fertilized rangelands. Bulletin 455. Logan, UT: Utah State University Agricultural Experiment Station; 1965. 35 p.
- Cook, C. Wayne. Development and use of foothill ranges in Utah. Bulletin 461. Logan, UT: Utah State University Agricultural Experiment Station; 1966a. 47 p.
- Cook, C. Wayne. Herbicide control of rabbitbrush and sagebrush in mixed stands. *Utah Science*. Logan, UT: Utah State University Agricultural Experiment Station; 1966b; 27: 9-10, 23.
- Cook, C. Wayne; Harris, Lorin E. Nutritive value of cheatgrass and crested wheatgrass on spring ranges in Utah. *Journal of Range Management*. 5: 331-337; 1952.
- Cook, C. Wayne; Leonard, Paul D.; Bonham, Charles D. Rabbitbrush competition and control of Utah rangelands. Bulletin 454. Logan, UT: Utah State University Agricultural Experiment Station; 1965. 28 p.
- Cook, C. Wayne; Stoddart, L. A. Seeding ranges to grass. *Utah Science*. Logan, UT: Utah State University Agricultural Experiment Station; 1947; 8: 10-12.
- Cook, C. Wayne; Stoddart, L. A. Seeding ranges to grass requires proper methods and hardy varieties. *Utah Science*. Logan, UT: Utah State University Agricultural Experiment Station; 1950; 11: 52-53, 56.
- Cook, C. Wayne; Stoddart, L. A. Survival of wheatgrass on sagebrush range depends on methods of seeding as well as weather conditions. *Utah Science*. Logan, UT: Utah State University Agricultural Experiment Station; 1951; 12: 43, 58-60.
- Cook, C. Wayne; Stoddart, L. A. Improve foothill ranges. *Utah Science*. Logan, UT: Utah State University Agricultural Experiment Station; 1959; 20: 5-6, 18.
- Cook, C. Wayne; Stoddart, L. A. Nutrient intake and livestock responses on seeded foothill ranges. *Journal of Animal Science*. 20: 36-41; 1961.
- Cook, C. Wayne; Stoddart, L. A.; Sims, Phillip L. Effects of season, spacing, and intensity of seeding on the development of foothill range grass stands. Bulletin 467. Logan, UT: Utah State University Agricultural Experiment Station; 1967. 73 p.
- Ferguson, Robert B.; Furniss, Malcolm M.; Basile, Joseph V. Insects destructive to bitterbrush flowers and seeds in southwestern Idaho. *Journal of Economic Entomology*. 56: 459-462; 1963.
- Frischknecht, Neil C. Effect of presowing vernalization on survival and development of several grasses. *Journal of Range Management*. 12: 280-286; 1959.
- Frischknecht, Neil C. Contrasting effects of big sagebrush and rubber rabbitbrush on production of crested wheatgrass. *Journal of Range Management*. 16: 70-74; 1963.
- Frischknecht, Neil C. How far will halogeton spread? *Journal of Soil and Water Conservation*. 22: 135-139; 1967.
- Frischknecht, Neil C. Factors influencing brush invasion of crested wheatgrass range. *Bulletin of the Ecological Society of America*. 43(3): 53; 1962. Abstract.
- Frischknecht, Neil C. Factors influencing halogeton invasion of crested wheatgrass range. *Journal of Range Management*. 21: 8-12; 1968a.
- Frischknecht, Neil C. Factors influencing production of flower stalks in *Agropyron cristatum*. Provo, UT: Brigham Young University; 1968b. 67 p. Ph.D. dissertation.

- Frischknecht, Neil C. Biological methods: a tool for sagebrush management. In: The sagebrush ecosystems: a symposium. Logan, UT: Utah State University Press; 1978a: 121-128.
- Frischknecht, Neil C. Effects of grazing, climate, fire, and other disturbances on long-term productivity of sagebrush-grass ranges. In: Hyder, D. N. ed. Proceedings of the first international rangeland congress. Denver, CO: Society for Range Management; 1978b: 633-635.
- Frischknecht, Neil C.; Baker, Maurice F. Voles can improve sagebrush rangelands. *Journal of Range Management*. 25: 466-468; 1972.
- Frischknecht, Neil C.; Bleak, Alvin T. Encroachment of big sagebrush on seeded range in northeastern Nevada. *Journal of Range Management*. 10(4): 165-170; 1957.
- Frischknecht, Neil C.; Harris, Lorin E. Grazing intensities and systems on crested wheatgrass in central Utah: response of vegetation and cattle. Technical Bulletin 1388. Washington, DC: U.S. Department of Agriculture, Forest Service; 1968. 47 p.
- Frischknecht, Neil C.; Harris, Lorin E. Sheep can control sagebrush on seeded range. *Utah Science*. Logan, UT: Utah State University Agricultural Experiment Station; 1973; 34: 27-30.
- Frischknecht, Neil C.; Harris, Lorin E.; Cook, C. Wayne. The Benmore experimental range. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1964. 13 p.
- Frischknecht, Neil C.; Harris, Lorin E.; Woodward, Harry K. Cattle gains and vegetal changes as influenced by grazing treatments on crested wheatgrass. *Journal of Range Management*. 6: 151-158; 1953.
- Harris, Lorin E.; Frischknecht, Neil C.; Stewart, George; Bennett, James A.; Woodward, Harry K. Crested wheatgrass provides excellent spring pasture for beef cattle. *Utah Science*. Utah State University Agricultural Experiment Station; 1950; 11: 71, 93-94.
- Harris, Lorin E.; Frischknecht, Neil C.; Sudweeks, Earl M. Extended grazing of crested wheatgrass by cattle: can it be successfully used in summer? *Utah Science*. Logan, UT: Utah State University Agricultural Experiment Station; 1965; 26: 14-17.
- Harris, Lorin E.; Frischknecht, Neil C.; Sudweeks, Earl M. Seasonal grazing of crested wheatgrass by cattle. *Journal of Range Management*. 21: 221-225; 1968.
- Harris, Lorin E.; Raleigh, Robert; Frischknecht, Neil C.; Bennett, James A. Cattle gains and vegetal changes as influenced by grazing treatments on crested wheatgrass. Proceedings of Western Section of American Society of Animal Production. 8: 1-6; 1957.
- Havertz, David S. Nematode pathogenicity to crested wheatgrass (*Agropyron cristatum*) at U.S. Forest Service Experiment Station, Benmore, Utah. Salt Lake City, UT: University of Utah; 77 p. 1957. M.S. thesis.
- Kearl, Leonard C.; Frischknecht, Neil C.; Harris, Lorin E. Wheatgrass, native grass, and forest grazed by cattle. Proceedings of Western Section of American Society of Animal Science. 22: 63-69; 1971.
- Keck, Wendell M.; Frischknecht, Neil C. A well-managed range boosts beef returns. *Utah Farmer*. 88: 34; 1968.
- Kilpatrick, H. M. Heavy grazing during fall and early winter improves sagebrush-grass range. In: Range and livestock management. Reno, NV: University of Nevada Press; 1965.
- Knowlton, George F. Range entomology: an important problem of the west. Logan, UT: Utah State University Extension Services; 1966; Mimeograph Series 84. 5 p.
- Leonard, Paul D. The influence of *Chrysothamnus nauseosus* on production and vigor of *Agropyron cristatum* and *Agropyron elongatum*. Logan, UT: Utah State University; 53 p. 1964. M.S. thesis.
- McArthur, Durant; Tiernan, Charles F.; Welch, Bruce. Subspecies specificity of gall forms on *Chrysothamnus nauseosus*. *Great Basin Naturalist*. 39: 81-87; 1979.
- McKell, Cyrus M.; Chilcote, William W. Response of rabbitbrush following removal of competing vegetation. *Journal of Range Management*. 10: 228-230; 1957.
- Mitchell, George W. Nutritive value of Russian wildrye, crested wheatgrass, and intermediate wheatgrass grazed by cattle on Utah foothill ranges. Logan, UT: Utah State University; 47 p. 1969. M.S. thesis.
- Mueggler, W. F. Voles damage big sagebrush in southwestern Montana. *Journal of Range Management*. 20: 88-90; 1967.
- Nichols, D. W. Small rodent populations and biomass in three sagebrush communities of Rush Valley. Utah. Provo, UT: Brigham Young University; 1972. 91 p. M.S. thesis.
- Nichols, D. W.; Smith, H. D.; Baker, M. F. Rodent populations, biomass, and community relationships in *Artemisia tridentata* in Rush Valley. *Great Basin Naturalist*. 35: 191-202; 1975.
- Parker, Ronald D. A study of the effects of two conversion treatments on pinyon-juniper vegetation in Utah. Provo, UT: Brigham Young University; 1971. 255 p. Ph.D. dissertation.
- Roberts, Dean L. Economics of carry-over forage production, increased grazing season length, and increased livestock production from rangeland fertilization. Logan, UT: Utah State University; 1977. 76 p. M.S. thesis.
- Stenquist, Norris J.; Bennett, James A. Optimizing calf weaning weight. Pamphlet EC 395. Logan, UT: Utah State University, Cooperative Extension Service; 1981. 8 p.
- Stoddart, L. A.; Cook, C. Wayne. What species of grass for range seeding? *Utah Science*. Logan, UT: Utah State University Agricultural Experiment Station. 1950; 11: 72-73, 84.
- Tingey, Ward M.; Jorgensen, Clive D.; Frischknecht, Neil C. Thrips of the sagebrush-grass range community in west-central Utah. *Journal of Range Management*. 25: 304-308; 1972.
- Vallentine, John F. Look more to wheatgrasses as spring graze. *Utah Cattleman*. 2: 5. 13-14; 1959.

Walker, Rudger H. Benmore area location of beef cattle investigations. Utah Science. Logan, UT: Utah State University Agricultural Experiment Station; 1944; 5: 6-7.

Warrum, Noble. History of Utah since statehood. Salt Lake City, UT: S. J. Clarke Publishing Company; 1919. 4 vol.

APPENDIX A: HISTORY OF BENMORE

Situated at the foot of the Sheeprock Mountains in west-central Utah, the lands in Rush Valley have experienced over a century of agricultural uses. Like similar areas in the West, this region has witnessed the ebb and flow of human impact on the environment.

Utah's early settlers were farmers first, then ranchers. Early herds were small and most cows provided milk and cheese; beef cattle were much less numerous. Unique among Western States, Utah's ranges were not heavily stocked with Texas longhorns and there were few large livestock operations. The Mormons did not import appreciable numbers of livestock in the mid-1800's. The Mormon Church itself advocated only small herds that could be well cared for and protected near towns from marauding Indians (Anonymous, n.d.).

Benmore was named for two families that exerted a strong influence on the history of Rush Valley: the Bennions and the Skidmores. Arriving in Salt Lake City in 1847, Samuel Bennion settled in what is now known as the Taylorsville area. Bennion's interests were primarily in farming, although he soon began to acquire some livestock. Because livestock herds were small (usually less than 50 head), a cooperative system of management developed among owners. Samuel Bennion joined with a group of other livestock owners in Taylorsville and made a trip in the mid-1850's across the Oquirrh Mountains. Their purpose was to investigate the potential of neighboring Rush Valley for livestock grazing (Bennion 1931). At this time, livestock cooperatives freely ranged their animals on any open lands available, often moving their livestock from one valley to another as the forage was used up (Warrum 1919).

Impressed by the abundance of grass he saw in Rush Valley, Bennion moved his livestock interests into the area in 1858 (Bennion 1931). At this time, western wheatgrass was the predominant species in the valley. According to early records, native grasses were vigorous and occupied both the valleys and benchlands so exclusively and grew so abundantly that it was frequently cut and stacked as hay for winter feed. However, some people scoffed at such efforts, believing that the supply of forage was inexhaustible and such reserves would never be needed. History proved them wrong. Notably, early settlers reported that sagebrush was not prevalent in the valley bottoms, but, like pinyon and juniper, was largely restricted to the foothills (Anonymous n.d.).

In the early years there was little competition for forage between livestock owners, but as numbers of animals increased the range began to show signs of strain. As early as the 1850's, settlers were exhorted to keep their herds small. **The Deseret News** of January 14, 1857, wrote:

Economy dictates the keeping only such and so many animals as each individual can profitably manage and provide for without depending upon the great uncertainty of winter range. On some ranges cattle are already dying of starvation.

But warnings such as these went largely unheeded. By the 1870's, upwards of 25,000 cattle and horses and an undetermined number of sheep were being summered and wintered in Rush Valley and adjacent Skull Valley (Anonymous n.d.). In the search for more grass, operators moved their herds from one valley to another. Yet, the supply of natural meadow grasses was soon inadequate to the growing herds and advancing frontiers of settlement. Areas near settlements, especially, were too heavily grazed and left nothing to be cut for winter. The depleted range spread in concentric circles from towns anxious to protect their animals from theft. Still, settlers maintained their herds or increased them and ranged their animals farther from towns in search of adequate forage (Anonymous n.d.). Soon, however, ranges where stock could be grazed year-round were exhausted. Given this pattern of continuous overstocking, the native herbaceous species declined and gave way to sagebrush and rabbitbrush.

By 1863, the Bennion livestock interests were well established, but the valley, which reportedly could support almost 10,000 head of livestock (cattle, horses, and oxen) year-round in the late 1850's, was being invaded by sagebrush and juniper. Still, the change was slow and the Bennions and others continued to run large herds in the valley.

In Utah, the era of cooperative herds comprised of many small operators was quickly coming to an end. The 1880's witnessed a consolidation of herds into the hands of a few individuals. This transformation was hastened by the invention of barbed wire in 1881 by Glidden and Ellwood, which brought the days of the free, open range to an end. In addition, droughty summers followed by harsh winters in the mid-1880's (the Great White Disaster) forced many settlers to reduce herd size or sell out completely. The Bennions became one of the few large livestock owners.

About the turn of the century, Rush Valley was considered suitable for another large-scale economic enterprise that was sweeping the West—dry farming. Rush Valley's second most prominent family entered at this time: the Skidmores. In 1905, Charles H. Skidmore and his brother Justin organized the Rush Valley Farming Company, and bought up 10,000 acres (4 047 ha) of land in the valley. The sagebrush-grass range was plowed and dry farms established. Others followed their example. In 1908, more land was acquired but, as before, little of it was irrigated. Winter wheat was planted where dense stands of sagebrush once stood, and when rainfall was good, yields from these farms were fair to good. Yet, during dry years, which occurred frequently, dry farming proved to be highly unprofitable. Many of these farms were abandoned and subsequently taken over by sagebrush.

From 1920 on, the cultivated area in Rush Valley declined in size, especially because the demand for wheat had fallen off drastically after World War I. The area languished, and land that had once supported thousands of head of livestock could scarcely support one-tenth as many in 1924. The sagebrush had taken over the abandoned farm lands so densely that a person had difficulty even walking through the area.

With slightly improved economic conditions in the mid-1920's, farmers moved into the valley, plowed the dense stands of sagebrush, and tried dry farming once more. But nature was conspiring against them. While the long-term average annual rainfall in Rush Valley is almost 13 inches (33 cm), between 1928 and 1935 the average was scarcely more than 9 inches (23 cm)—an amount far below the needs for successful dry farming. In fact, most of the years between 1925 and 1935 were drought years. Thus, farm lands were again abandoned, and sagebrush reinvaded, easily out-competing the depleted perennial grasses.

Through all these years, the Bennions struggled to maintain their livestock interests in Rush Valley. One of the Bennion clan was the first to experiment with management techniques in the early 1920's in an attempt to restore the range to its former productivity. Israel Bennion burned sections of sagebrush during dry seasons and then held livestock off these areas during the growing season. Bennion found that with a few years' protection, the whole burnt area would return to bluestem and bunchgrass. If not protected from grazing, however, weeds and sagebrush quickly reappeared (Bennion 1924).

While Bennion's efforts were noted, they were not generally accepted as good management techniques. Few people really understood enough about rangelands to know what to do. Thus, much of Rush Valley remained dominated by sagebrush that had once been confined to the foothills.

Livestock interests were not faring well. After World War I, especially, there were too many animals on the ranges in Utah and they could not be sold. In 1920 alone, Utah owners reported that over 500,000 head of cattle crowded spring-fall ranges that were already seriously depleted. By the 1930's the depleted, drought-stricken, and poorly managed land led to low calf and

lamb crops, lessened carrying capacity, and even poorer range condition. Livestock numbers in Utah up to the 1930's were:

Year	Cattle	Sheep
1885	200,000	1 million
1895	420,000	2 million
1905	350,000	2.6 million
1920	500,000	2.2 million
1930	450,000	3.0 million

Ironically, as the capacity of the range to support livestock declined, numbers of animals were increasing.

As one Bennion pioneer put it:

Rush valley was all a beautiful meadow of grass when we came here with stock in 1860; but in less than 15 years she was all et out, and we had to move to Castle Valley. There you have the history of western grazing in a nutshell. If the range be considered the principal part of the grazers' capital stock, then we grazers have just about finished consuming our capital (Anonymous n.d.).

This pattern of development in Rush Valley was being acted out all over the Western United States. Combined with the Great Depression and "dustbowl" conditions in several Western States, the Federal Government created the necessary machinery to prevent this recurrence of alternate settlement and desertion. Between 1934 and 1936, the Agricultural Resettlement Administration established the Central Utah Purchase Project, which acquired land in two old dry farm areas in Utah—Benmore in Rush Valley and Widtsoe in southern Utah near Panguitch. Of the 45,000 acres (18 211 ha) purchased in Rush Valley, over 3,200 acres (1 295 ha) were set aside for research purposes. The experimental site was given the name "Benmore" after the valley's foremost residents and after the small abandoned community of the same name.

APPENDIX B: LIST OF COMMON AND SCIENTIFIC NAMES

Common name	Scientific name
Trees:	
Pinyon pine	<i>Pinus monophylla</i>
Utah juniper	<i>Juniperus osteosperma</i>
Shrubs:	
Antelope bitterbrush	<i>Purshia tridentata</i>
Big sagebrush	<i>Artemisia tridentata</i>
Douglas rabbitbrush	<i>Chrysothamnus viscidiflorus</i>
Greasewood	<i>Sarcobatus vermiculatus</i>
Green rubber rabbitbrush	<i>Chrysothamnus nauseosus</i> ssp. <i>graveolens</i>
Mountain rubber rabbitbrush	<i>Chrysothamnus nauseosus</i> ssp. <i>salicifolius</i>
Rubber rabbitbrush	<i>Chrysothamnus nauseosus</i>
Shadscale	<i>Atriplex confertifolia</i>
Threadleaf rubber rabbitbrush	<i>Chrysothamnus nauseosus</i> ssp. <i>consimilis</i>
White rubber rabbitbrush	<i>Chrysothamnus nauseosus</i> ssp. <i>albicaulis</i>
Forbs:	
Bur buttercup	<i>Ranunculus testiculatus</i>
Deathcamas	<i>Zygadenus paniculatus</i>
Desert globemallow	<i>Sphaeralcea</i> spp.
False dandelion	<i>Agoseris glauca</i>
Groundsel	<i>Senecio integerrimus</i>
Halogeton	<i>Halogeton glomeratus</i>
Hawksbeard	<i>Crepis acuminata</i>
Hoary phlox	<i>Phlox hoodii</i>
Locoweed	<i>Astragalus cibarius</i>
Longleaf phlox	<i>Phlox longifolia</i>
Low fleabane	<i>Erigeron pumilus</i>
Lupine	<i>Lupinus</i> spp.
Pepperweed	<i>Lepidium perfoliatum</i>
Russian thistle	<i>Salsola kali</i>
Utah sweetvetch	<i>Hedysarum boreale utahensis</i>
Grasses:	
Bluebunch wheatgrass	<i>Agropyron spicatum</i>
Bottlebrush squirreltail	<i>Sitanion hystrix</i>
Bulbous bluegrass	<i>Poa bulbosa</i>
Cheatgrass	<i>Bromus tectorum</i>
Crested wheatgrass	<i>Agropyron desertorum</i>
Delmar fall wheat	<i>Triticum aestivum</i>
Fairway wheatgrass	<i>Agropyron cristatum</i>
Gaines fall wheat	<i>Triticum aestivum</i>
Great Basin wildrye	<i>Elymus cinereus</i>
Indian ricegrass	<i>Oryzopsis hymenoides</i>
Intermediate wheatgrass	<i>Agropyron intermedium</i>
Mountain rye	<i>Secale montanum</i>
Pubescent wheatgrass	<i>Agropyron tricophorum</i>
Russian wildrye	<i>Elymus junceus</i>
Sandberg bluegrass	<i>Poa secunda</i>
Slender wheatgrass	<i>Agropyron trachycalum</i>
Smooth brome	<i>Bromus inermis</i>
Tall oatgrass	<i>Arrhenatherum elatius</i>
Tall wheatgrass	<i>Agropyron elongatum</i>
Thickspike wheatgrass	<i>Agropyron dasystachyum</i>
Western wheatgrass	<i>Agropyron smithii</i>
Winter rye	<i>Secale cereale</i>

APPENDIX B: (con.)

Mammals:

Chisel-toothed kangaroo rat	<i>Dipodomys microps</i>
Nuttall cottontail	<i>Sylvilagus nuttallii</i>
Deer mouse	<i>Peromyscus maniculatus</i>
Great Basin pocket mouse	<i>Perognathus parvus</i>
Blacktail jackrabbit	<i>Lepus californicus</i>
Least chipmunk	<i>Eutamias minimus</i>
Long-tailed vole	<i>Microtus longicaudus</i>
Western harvest mouse	<i>Reithrodontomys megalotis</i>

Birds:

Brewer's sparrow	<i>Spizella breweri</i>
Chipping sparrow	<i>Spizella passerina</i>
Common bushtit	<i>Psaltiriparus minimus</i>
Gray flycatcher	<i>Empidonax wrightii</i>
Horned lark	<i>Eremophila alpestris</i>
Housefinch	<i>Carpodacus mexicanus</i>
Lark sparrow	<i>Chondestes grammacus</i>
Mountain bluebird	<i>Sialia currucoides</i>
Plain titmouse	<i>Parus inornatus</i>
Raven	<i>Corvus corax</i>
Sage thrasher	<i>Oreoscoptes montanus</i>
Scrub jay	<i>Aphelocoma coerulescens</i>
Vesper sparrow	<i>Pooecetes gramineus</i>
Western meadowlark	<i>Sturnella neglecta</i>

Insects:

Aphid	<i>Aphis</i> spp.
Blackgrass bug	<i>Labops hesperius</i>
Cicada	<i>Cicadidae</i> spp.
Leaf beetle	<i>Trirhabda attenuata</i>
Leaf beetle	<i>Trirhabda pilosa</i>
Lepidopterous insects	<i>Septeroa</i> spp.
Nematode	<i>Nothotylenchus acris</i>
Nematode	<i>Tylenchus davainii</i>
Nematode	<i>Tylenchorhynchus dubius</i>
Sagebrush defoliator moth	<i>Aroga websterii</i>
Thrip	<i>Anaphotrip zaeae</i>
Thrip	<i>Aptinothrip rufus</i>
Weevil	<i>Myrmex lineata knowletoni</i>
Western flower thrip	<i>Frankliniella occidentalis</i>



Astroth, Kirk A.; Frischknecht, Neil C. Managing Intermountain rangelands—research on the Benmore Experimental Range, 1940-84. General Technical Report INT-175. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 44 p.

This paper summarizes research findings from 44 years of research on the Benmore Experimental Range in central Utah and brings together findings previously available in over 80 published and unpublished reports. It provides recommendations for the rehabilitation or improvement, management, and grazing of sagebrush rangelands.

KEYWORDS: range management, range improvement, sagebrush, rangelands, crested wheatgrass, brush control, planting methods, grazing improved ranges

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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